AN INVESTIGATION INTO CERTAIN ECONOMIC ASPECTS OF INTEGRATED LOGISTICS SUPPORT PLANNING FOR UNITED STATES NAVY WEAPONS SYSTEMS

David Charles Stumbaugh

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by
David Charles Stumbaugh

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Doctoral Committee:

Professor Martin R. Warshaw, Chairman
Associate Professor Saul H. Hymans
Professor Franklin G. Moore
Professor J. Philip Wernette
Associate Professor William J. Wrobleski

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INTRODUCTION

> Improving on the allocation of 10 percent of the national GNP is enough to keep more than a few economists busy assisting the military services and the Secretary of Defense.[1]

Government Decision-Making

Decision-making in government in general and in the military in particular is not subject to the same influences as it is in private industry. Consequently, in any discussion of management problems in the military too close a correspondence with industry problems should not be assumed.[2] Certain very substantial differences exist. For example:

1. There is no clear cut profit motive in the military. When business management has to decide how to allocate scarce funds the expected revenues, costs and profits of potential

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[1]Stephen Enke, "Using Costs to Select Weapons," American Economic Review, May, 1965, p. 426.

[2]David Novick and G. H. Fisher discuss this problem at more length in "The Role of Management Tools in Making Military Decisions," Armed Forces Management, September, 1956, p. 44.

alternatives can be compared. All of these variables can be expressed in terms of a common denominator -- dollars. The military decision-maker is in a somewhat different situation. He must somehow value the "military worth" of various alternatives. This can be a difficult task.

2. There is a problem involved in defining precisely the "product" involved in many military operations. In order to use purely quantitative techniques this, of course, would be essential.
3. The motivations of a military decision-maker are different from those of his counterpart in business and bargaining to achieve desired goals assumes a role of much greater importance. A measure of "efficient" operation is thus more difficult to establish.
4. There is the lack of a free market mechanism which is designed to reveal preferences to the military manager of the citizen in his role as a consumer of governmental services. It is, in general, harder to determine consumer wants in the public than in the private sector of the economy.

Inasmuch as these differences exist, it is understandably more difficult to formulate concepts of management control for

government executives than for those in industry. The budgetary process in government cannot operate to insure efficient activity in the same manner that the price mechanism and competition enforce efficiency in industry.[3] Yet choices do have to be made and resources are limited in the public sector, including the defense establishment. Despite the differences referred to, there is some common ground and the basic economic problem in both sectors remains that of making the best use of scarce resources. One certainly should not claim too much for public budgeting in helping to achieve this end. However, "the budgetary process can make for better-informed judgment concerning the allocation of government resources and can encourage the more effective use of resources devoted to particular purposes."[4]

Economic theory has always been concerned with the problem of resource use, but only in the last few years has any real attempt been made to apply existing theory to the problems involved in making military expenditures through this budgetary process.[5] Since the

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[3]See the discussion concerning operation of the market mechanism in Paul A. Samuelson, Economics (7th ed.; New York: McGraw Hill Book Company, 1967), pp. 42, 57-64.

[4]Jesse Burkhead, Government Budgeting (New York: John Wiley & Sons, Inc., 1956), p. 37.

[5]Charles J. Hitch and Roland N. McKean, The Economics of Defense in the Nuclear Age (Cambridge, Mass.: Harvard University Press, 1960), p. 105.

early 1960's, systematic quantitative analysis has been more rigorously employed in the allocation process to aid military decision-making where, due to the complexities of the problems involved, its role might be considered potentially more important even than in the private sector of the economy.

Development of Integrated Logistic Support Planning

The formal concept of Integrated Logistics Support Planning (ILSP) in the Department of Defense was instituted during 1964. Since that time a great deal has been written on how the system is designed to work from a theoretical standpoint.[6] Much less has been done to provide a definite organization across functional lines within which the system can operate. Moreover, relatively little specific guidance has been provided to those with decision-making responsibilities as to how procedures are to be implemented particularly as regards the the use of the techniques of economic analysis, statistical decision theory and the more recent concepts of business logistics management.

The organizational problem involved in implementing ILSP procedures is a formidable one, but one which is largely outside the

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[6]U. S., Department of Defense, Directive 4100.35, Development of Integrated Logistic Support for Systems and Equipment (Washington, D. C.: Department of Defense, June 19, 1964) officially established policies and objectives and assigned responsibility for carrying out the program. The scope and meaning of ILSP and related logistics concepts are discussed in more detail in Chapter II, infra.

scope of this paper. The focus here is rather on adding to the "bag of tools" of those who must make resource allocation decisions in a military setting so that they may be more competent to consider the economic implications of logistic decisions. The Chief of Naval Material, United States Navy, in fact, indicated the desirability of this when he said:

> The introduction of the logistical view into the research and development process at an early stage is one aspect of logistics which is rapidly becoming more prominent and one which will have an important role in the years ahead. It requires that we develop large numbers of individuals who can "think logistics" across the whole life span of each weapon system.[7]

Accordingly, the study of the Integrated Logistic Support concept which follows investigates procedures aimed at using military support in the most effective and efficient manner.[8] Before proceeding, however, it would be well to distinguish between the terms economy and efficiency. These two terms may actually be considered to be mirror images of each other.[9] Economy thus means to achieve a

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[7]I. J. Galantin, keynote address presented at the Navy Supply Conference, Washington, D. C., May 4, 1965.

[8]See Logistics Systems Management, Inc., Maintenance Engineering Analysis Procedures (MEAPS) Guide (Washington, D. C.: Logistics Systems Management, Inc., 1966), p. 1-1 for a discussion of the meaning of these concepts in a military setting.

[9]Donald Stevenson Watson, Price Theory and Its Uses (2nd ed.; Boston, Mass.: Houghton Mifflin Company, 1968), pp. 10-11.

given objective with expenditure of the fewest resources (least costs) whereas efficiency means to achieve the maximum possible benefits from a given input of resources. Such will be the meanings intended when these terms are subsequently used.

General considerations. -- A few additional considerations should also be noted as regards this study of ILSP. One is that the motivation of military decision-makers should not be too lightly dismissed despite the differences previously referred to with respect to the private sector of the economy. The Deputy Secretary of Defense has recently stated in this regard that "Managers in the Department of Defense have one motivation going for them that managers elsewhere do not. They are directly committed to a cause that supports the very foundations of government -- the preservation of government itself."[10] Given this motivation, then, it is important that defense managers be provided tools which, in the absence of a true market mechanism, can be used to improve resource allocation decisions.

In terms of its over-all place in the scheme of national economic activity, defense has been called "...the archetype of a public good, a good that is most suitable for outright production by

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[10] David R. Packard, "The Qualities of Good Management," Defense Management Journal, Spring, 1969, p. 1.

the national government. . . ."[11] The theory of public goods and their production is of interest in a general consideration of military resource allocation, but is not in its entirety an immediate concern of this study.[12] The main point of interest here is that a public good such as national defense cannot be effectively supplied through the market mechanism and, therefore, it is necessary to devise other means of supply and other tests of efficiency. These are subjects with which this research deals.

Information on specific systems and equipment involved in ILSP is presented below in an unclassified manner and with due regard for proprietary information. Whenever possible, specific systems, equipment, and contractors are identified and actual cost and performance data used. Where appropriate, examples are used to further clarify points being made.

Need for the Study

One observer has written that [in the military] "Logistics support historically has had little glamour. It has been relegated to

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[11] Martin J. Bailey, "The Market Mechanism in the Defense Department," in Issues in Defense Economics, ed. by Roland N. McKean (New York: Columbia University Press for the National Bureau of Economic Research, 1967), p. 175.

[12] A brief summary of the theory of public goods as it applies to national defense is included in Appendix A for reference purposes.

a secondary status and called upon only when a specific need or emergency arose."[13] During the period of World War II and for several years thereafter, defense planning in general was geared to a concept of harnessing the vast productive power of the United States to overwhelm the military potential of any aggressor.[14] This planning was based on the assumption that adequate time would always be available to bring the Nation's productive power to full force and that the country would be able to maintain at least an adequate defense until such time as this was accomplished. In this atmosphere, attention was focused primarily on production and delivery of weapon systems. Responsibility for the post-delivery logistics support of these systems was often overlooked or given only cursory consideration. Likewise the total cost of this support received little attention.

In part due to the achievements of Soviet science, a wide range of new weapons began appearing on the drawing boards during this period. A successful launching of the Soviet sputnik in 1957 ushered in the space age and a whole new era of technology. Faced

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[13]Edward J. Shaughnessy, A Preliminary Review of DOD Directive 4100.35 of June 19, 1964 "Development of Integrated Logistic Support for Systems and Equipment" (Washington, D. C.; Planning Research Corporation, November, 1964), p. 5.

[14]Murray A. Geisler, The Impact of Changing Defense on Logistics Requirements (Santa Monica, Calif.: The RAND Corporation, December, 1963), p. 1.

with the threat of possible overhaul by the Soviets, speed of production of these ever more complex and expensive weapons appeared to assume primary importance.[15] If an optimal mix of the three dimensions of development effort -- time, quality, and cost -- could not be quickly achieved, then emphasis clearly was to be placed on speed of development.

A turning point in military strategy considerations also evolved during the 1950's. With the development of more sophisticated, versatile weapons and equipment, emphasis began to change from reliance on the relatively slow build-up of a massive response to more dependence on forces in being. Conviction began to grow that military readiness and therefore national security would depend in the future on weapon systems in current operation. Should another major conflict occur the issue might well be decided almost immediately with weapons then available. A flexible capability was also felt desirable to deal with a whole spectrum of conflicts ranging from counter-insurgency to those of a "brush fire" nature. This desire to increase the fire power and mobility of the armed forces through the development of a large inventory of modern sophisticated weapon systems and equipment is understandable and probably necessary.

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[15] A. A. Giordano, "Logistical Implications of Weapon System Design Decisions: Integrated Logistic Support for Navy Weapon Systems," Naval Engineers Journal, April, 1966, p. 194.

The process does, however, create new and more difficult problems for the logistics management function.[16] Two major problems, in particular, arise if the weapon systems and equipment are new and complex: (1) they are then likely also to be expensive, and (2) support requirements will not have been demonstrated in actual use.

With the introduction of increasingly more complex weapon systems into the arsenal, it soon became apparent that maintainability and reliability considerations had vastly increased in importance. For example, Giordano notes that "...the operational success of even routine naval missions is now almost totally hostage to the successful performance of sophisticated weapon systems."[17] In addition, it has become increasingly apparent that maintainability and reliability requirements have to be in effect "built in" to the equipment in the design stage to insure adequate supportability.

Logistic support of the operating forces has, of necessity, always been carried out. A chart showing the organizations currently engaged in this function for the Navy is included for reference as Appendix B. This support planning has in the past, however, been devoid to a large extent of quantitative methodologies and measured

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[16]Charles J. Zwick, Logistics Modernization (Santa Monica, Calif.: The RAND Corporation, August, 1964), p. 2.

[17]Giordano, "Logistical Implications of Weapon System Design Decisions," p. 194.

consideration of available alternatives over the equipment's life cycle. A new weapon system is born in an environment of complex interactions among several influences. These influences include: "The Threat" as defined by government intelligence; present capability to respond as calculated by military planners; state of available technology as determined by scientists; and funds made available by Congress and the Administration.[18]

A basic acknowledgement contained in the Integrated Logistic Support Planning (ILSP) concept is that any given weapon system or equipment design automatically generates certain logistical support considerations and that these considerations are affected by interaction among the influences referred to above. There is thus a continuing need for the development of new analytical tools and applications of economic analysis to obtain the maximum advantage from logistics support dollars spent. This study is concerned with that need and suggests areas where the planning and decision-making process might be improved. Attention is confined primarily to logistics support planning in the United States Navy, through evaluation of certain aspects of the concept of ILSP.

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[18] Logistics Management Institute, Methods for Evaluating the Cost/Effectiveness of Alternate Support Plans for Major Weapon Systems (Washington, D. C. : Logistics Management Institute, September, 1965), p. 30.

The problem of sharply increasing costs. -- Rising costs of modern sophisticated weapon systems have also been instrumental in forcing the use of analytical tools in military allocation decisions. Discussing this point Enthoven points out that:

> Whether we like it or not, we have only a limited amount of goods and services available at any one time. Our gross national product, though large, is limited. We have only a finite number of manhours available for all forms of defense activity. Moreover, there are other needs besides defense: feeding, clothing, and housing our population, educating our children, cultivating our minds, fighting disease, and so on. Therefore, in peace or in war, only a limited amount of resources is available for defense. And if we wish to assure our freedom, it is important that we use those resources well.[19]

Because of the high cost of these systems, it is necessary to exercise tighter control over the weapon itself and also the support structure which backs it up. In Fiscal Year 1965, for example, over 25 percent of the budget for national defense was designated for maintenance and support of systems and equipment.[20] An appreciation for the magnitude of these support operations in the United States Navy can be obtained from the following:

> The Navy is a composite warfare system, an intricate mix of some 900 submarines and surface ships of many

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[19] Alain Enthoven, "Systems Analysis and the Navy," Naval Review 1965 (Annapolis, Md.: United States Naval Institute, 1964), p. 102.

[20] C. B. Moore, An Integrated Approach to Logistics Analysis (Fort Worth, Texas: General Dynamics, May, 1966), p. 1.

> types, 8000 aircraft of every kind and configuration, missiles, and 260 supporting shore activities, all manned by over 700,000 military personnel and more than 360,000 civilian personnel all contributing their special skills and qualities to a balanced force capable of highly mobile worldwide combat operations. Keeping this composite warfare system operating is a $15 billion-a-year operation. Keeping it supplied takes anywhere from half to two-thirds of that amount, depending on how the computation is made; in any event, it exceeds the annual income of the nation's railroad industry and approximates that of the entire telephone system.[21]

That the need for applying economic analysis to the planning of military activities is not likely to decrease in the near future is indicated by Clark when he states: "The events of the decade since World War II mark a qualitative change in the group structure of American democracy -- namely the acceptance on a 'permanent' basis of a large professional military establishment."[22] The Department of Defense, owning property valued in excess of $160 billion, is the wealthiest economic organization in the nation or the world, and 25 to 30 percent of the country's economic activity is tied in some manner to military spending.

As a practical consideration for military planners, moreover, the Department of Defense budget is coming under increasingly

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[21]U. S., Department of Defense, Supplying the Navy, NAVPERS 10487 (Washington, D. C.: Bureau of Naval Personnel, 1967), p. 3.

[22]John J. Clark, The New Economics of National Defense (New York: Random House, 1966), p. v.

close scrutiny in the Congress.[23] As the cost of weapon systems and their logistic support continues to rise, it may be expected that this trend will intensify. If in the future a major system is to be approved, it will have to present a sound economic as well as military effectiveness argument not only as regards initial procurement cost, but also as regards support costs as well.

A serious problem is that the expenditure of large sums for military procurement and support has not always resulted in the delivery of reliable and supportable equipment. Speaking of this problem, the former Air Force Deputy Chief of Staff for Material once complained that bomb navigation systems had been designed to do so much that they were not only too expensive, but also sometimes almost impossible to maintain.[24] As another example, a study presented to Congress showed that of a sample of thirteen major Air Force and Navy aircraft and missile programs initiated since 1955 at a total cost of $40 billion, less than 40 percent had produced sys-

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[23]For example, U. S., Congress, Joint Economic Committee, The Economics of Military Procurement, Joint Committee Print (Washington, D. C. : Government Printing Office, 1969), pp. 18-28, contains a critical evaluation of cost overruns on the C-5A Air Force long-range, heavy logistic aircraft.

[24]Mark F. Bradley, speech before the Los Angeles Chamber of Commerce, September 25, 1959.

tems with acceptable electronic performance.[25]

Since these weapon systems are extremely costly, it is essential in the interest of efficient allocation and use of military resources that design and development of new weapon systems and equipment proceed on a basis which balances a level of military readiness with its attendant cost. Former President Eisenhower has been quoted in this connection as stating in 1952 that: "... the foundation of military strength is economic strength. A bankrupt America is more the Soviet goal than an America conquered on the field of battle."[26]

Objective of the Study

Department of the Navy Directives and Instructions implementing Integrated Logistic Support Planning make it clear that:

1. The scope of ILSP applies to the acquisition of all systems and equipment by the Navy.[27]

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[25]U. S., Congress, Richard A. Stubbing, "Improving the Acquisition Process for High Risk Military Electronics Systems," 91st Cong., 1st sess., Feb. 7, 1969, Congressional Record, 115, S1450.

[26]Warner R. Schilling, Paul Y. Hammond and Glen H. Snyder, Strategy, Politics and Defense Budgets (New York: Columbia University Press, 1962), p. 390.

[27]U. S., Department of the Navy, SECNAV Instruction 4000.29, Development of Integrated Logistic Support for Systems and Equipments (Washington, D. C.: Headquarters Naval Material Command, August 19, 1966), p. 1.

2. An "Acquisition Manager" will be designated for every major system and will be charged not only with the responsibility for development and production of Navy equipment, but also with responsibility for "design and development of the related logistic support package."[28]
3. An assistant, or "logistician" will be assigned to the Acquisition Manager. He is to be responsible for "planning, development, acquisition, integration and execution of the Integrated Logistic Support Plan."[29]
4. Each system command, bureau and other organizational component participating in the acquisition and logistic support process shall be responsible to work with the designated system or equipment logistician.[30]

In view of the potentially large number of organizational entities and personnel that can become involved in logistic support planning for a weapon system or equipment, it should be helpful to indicate areas in which decision-making procedures can be aided

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[28] U. S., Department of the Navy, NAVMAT Instruction 4000.20, Integrated Logistic Support Planning Procedures (Washington, D. C.: Headquarters Naval Material Command, August 19, 1966), p. 1.

[29] *Ibid.*, p. 2.

[30] *Ibid.*, p. 3.

through increasing the understanding of those involved of certain concepts of economic analysis, statistical decision theory and business logistics management where these have application to the ILS process. Accordingly, the objective of this research is to investigate several areas where these concepts can be applied to help make the support planning decision clearer or more defensible, or at least to help the decision-maker to be more aware of these important considerations.

One Naval officer writing on the subject considers that the basic function of management is decision-making, a process he feels can be reduced to five basic steps: (1) awareness of the facts, (2) recognition of the problem, (3) analysis of available alternatives, (4) choice of an alternative, and (5) resulting action.[31] The general objective of this research is to assist the ILS planner in the first four steps, so that the fifth step, resulting action, might be rendered more sound from an economic standpoint. In a program involving the expenditure of large sums of money each year, any improvement in the decision-making process could have a substantial pay-off.

Specific objectives of this research, relating to the areas of investigation referred to above are:

1. To foster in ILS program managers a clear understanding of

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[31] J. S. Vishneski, Jr., "Management," Navy Supply Corps Newsletter, April, 1969, p. 17.

the economic principles involved in achieving an efficient allocation of resources devoted to weapon system support operations.

2. To investigate the potential use of Bayesian statistical decision theory in the ILS environment so that all available sources of information might be utilized in a systematic manner prior to the making of decisions involving the commitment of human, financial, and physical resources to support operations.
3. To investigate certain of the elements officially designated as comprising Integrated Logistics Support and to indicate areas in which the application of current concepts of business logistics management could result in new considerations being brought forward, particularly in the areas of inventory management and customer service levels (CSL).
4. To investigate the role of cost-benefit and cost-effectiveness analyses in the ILS decision-making process.

An important point which might be raised is that Integrated Logistic Support Planning does involve significant program control of the total weapon system and equipment acquisition and deployment process. Such control can in itself be expensive and require the employment of scarce resources. It has been estimated, for example, that management control of an approved defense program may amount to between 30 and 50 percent of the contract cost of a major

engineering or operational systems development program.[32] It is essential, therefore, that this planning be well considered. From the discussion above it is clear that in addition to the plan for operational performance of a new system, a companion plan for its logistic support is also required by the Department of Defense. As development and acquisition proceeds, these plans must be "meshed" if the total system is to achieve optimum effectiveness.[33] The objective of this research is to indicate tools and other relevant considerations for the benefit of those who are to be involved in the achievement of this meshing. The Assistant Secretary of the Navy (Installations and Logistics), indicating a need for such information, recently stated that in the Navy logistics system, a "statistical, economic approach to decision-making will continue and become more expansive."[34]

Hypotheses

The hypotheses of this study relate to specific areas of Integrated Logistic Support Planning. They are:

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[32] J. Lynn Helms, "The Impact of Government Program Control," speech given to the Armed Forces Management Association, Washington, D. C., September 1, 1965.

[33] Thomas D. Morris, keynote address presented at The Electronic Industries Symposium, Washington, D. C., March 7, 1968.

[34] Barry J. Shillito, "Assistant SECNAV Shillito Speaks on the Corps," Navy Supply Corps Newsletter, January 1, 1969, p. 15.

1. Certain micro-economic concepts applied to ILS problems can improve the allocation of resources by logistic decision-makers. These concepts include marginal and indifference curve analysis.
2. Bayesian statistical decision theory can be used in ILS situations and can be of valuable assistance by providing a means through which additional information can be brought to bear systematically on the problem with due regard being given to the cost of acquiring such information.
3. Some elements that now comprise ILS should be reevaluated and broadened in scope, particularly those that concern the costing of inventory and the use of the concept of customer service levels in establishing desired inventory quantities. Modern business logistics concepts can be brought to bear in these areas. The narrow approach at times now being used can result in cost estimates that are incomplete at best and that may result in misallocation of resources.
4. Cost-benefit and cost-effectiveness studies are important to ILS decision-making primarily because they help to focus attention on relevant areas that might otherwise be overlooked rather than because of their mathematical precision. In the allocation of support resources, the practical applicability of

cost-benefit analysis is somewhat limited due to immeasurable factors involved and the possibility of their being interpreted in a different manner by different analysts.

Research Methodology

The following procedure was followed during the investigative phase of this research:

1. A general review was conducted of management decision theory as used in the government and business logistics fields for application to military weapon system and equipment support planning. This literature is quite extensive and much of the theory involved has not been brought to bear on ILS problems.
2. Attendance was arranged at a formal three day Navy Integrated Logistics Support Concepts Course in Washington, D. C., sponsored by the Chief of Naval Material and conducted under Navy contract by Sterling Institute personnel. Material used in the course was prepared by the Sterling Institute, Defense and Aerospace Center, in association with Peat, Marwick, Livingston & Co. The general purpose and objectives of this course are important to the research carried out, and are therefore listed for information in Appendix C. This course provided a strong conceptual base for the study detailed herein.

3. The Naval Supply Systems Command in Washington D. C., is an "element manager" within the definition of Integrated Logistic Support directives. As such, an extensive ILS library is maintained and an ILS group has been established within the Development Branch of the Research and Development Division. On-the-site review and study of the material in this library and discussion with ILS group members was carried out. This formed the basis for understanding as to:

   a. The theoretical role of ILS within the support organization of the Navy, as shown in Appendix B.

   b. The way ILS actually is working in practice, and

   c. The potential for application of the concepts developed in this study to the ILS process.

4. Current Department of Defense and Navy guidelines and directives concerning criteria for use in evaluating investment decisions and the establishment of inventory levels were investigated to form the basis for the discussion in Chapter V of inventory policy and the importance of the concept of customer service levels in Navy business management.

Scope and Limitations of the Study

Integrated Logistic Support Procedures apply to all activities and all acquisitions within the Department of Defense. This study

of the ILS process, however, has been primarily limited to operations within the Department of the Navy and more specifically to the Naval Supply Systems Command, which is responsible for ILS supply support including spares and repair parts and also for transportation and handling that is used for logistics purposes.[35] Concentration thus is on support aspects of weapon system and equipment ownership although, as demonstrated in Chapter VII, acquisition costs must also be taken into account.

It has been stated by writers on the subject of defense management that a weapon system, such as a ballistic missile, has the following important characteristics:[36]

1. Availability: The probability that the missile will be available for launch when required.
2. Survivability: The probability that the missile will survive, given that it is fired upon by the enemy.
3. Reliability: The probability that the payload will attain the proper ballistic trajectory.

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[35] H. J. Lieberman, Research and Development in Integrated Logistics Support (Washington, D. C. : Naval Supply Systems Command, February 24, 1969), pp. 4-5.

[36] R. H. McMahan, Jr. and D. H. Taylor, "Central War Alternatives," in Defense Management, ed. by Stephen Enke (Englewood Cliffs, N. J. : Prentice-Hall, Inc., 1967), p. 117.

4. Penetration Probability: The probability that the warhead will penetrate the defenses, given that it arrives at the target and that the target is defended.

5. Kill Probability: The probability that the warhead will kill the target, given that it penetrates. This in turn is a function of (a) other weapon system characteristics such as yield and accuracy; (b) target characteristics such as hardness, accuracy of attacker's knowledge of its location, and so on; and (c) the kill criterion established by the offense.

6. Cost: The research and development, investment, operating, and basic support costs of each system as a function of the number purchased (author's italics).

Accepting this list, then, the scope of this study is limited primarily to characteristic number six, especially the support aspects, and to characteristics one and three, as they influence six.

The use of economic analysis in defense planning does have certain limitations, some of which have already been mentioned. Others which are important, but whose investigation is beyond the scope of this study, are:

1. The use of analytical economic analysis can lead to the elimination of some alternatives that involve the investment of resources in capabilities of low effectiveness, however, it cannot

aid in setting national priorities as, for example, helping to choose between expenditures for urban development and expenditures for national defense. Within any one homogeneous category, however, measurements and selections are possible.[37] For purposes of this study, it has been assumed that decisions as to desired military capabilities are being made through the political process and that the task which presents itself is to provide that capability in the most economic or "cost-effective" manner. Specifically, the analysis is primarily limited to a discussion of the cost of logistics support (as defined in Chapter II) of that capability once it is translated into hardware. Total life cycle costs, however, must always be given due attention.

2. Information deficiencies stemming from what Piekarz terms "inappropriate accounting conventions" at present seriously limit the potentialities for certain types of analyses in the Department of Defense.[38] This problem is recognized, however, and steps toward improvement are being made.[39]

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[37]Burkhead, Government Budgeting, p. 251.

[38]Rolf Piekarz, "Discussion of Defense Economics: Applying Economic Criteria," American Economic Review, May, 1965, p. 436. See also Hitch and McKean, The Economics of Defense in the Nuclear Age, p. 233 on the need for better accounting techniques.

[39]For example, see Robert N. Grosse and Arnold Proschan, "The Annual Cycle: Planning-Programming-Budgeting," in Defense Management, ed. by Enke, pp. 37-39.

3. The whole spectrum of Department of Defense-defense contractor relationships affects the distribution of goods and services in the military establishment. This management area requires a great deal of additional attention.[40] It has been assumed in this study that contractual methods have been adopted which, at least, will not interfere with attempts to employ analytical techniques to maximize output.

4. With the introduction of ever more sophisticated systems and equipment, the problems of military choice in the future may well increase in those areas in which systematic quantitative analysis is unable to provide "the" solution. Such problem areas include the establishment of objectives, uncertainties, and strategic choice.[41] Here again, this study assumes that the capability decision has already been made and that it is the task of economic analysis to assist in the evaluation of alternative methods for providing that capability.

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[40] For a discussion of some of these contractual problem areas, see the testimony of VADM H. G. Rickover in U. S., Congress, Joint Economic Committee, Economics of Military Procurement, Part 2, Hearings before the Subcommittee on Economy in Government, Joint Committee Print (Washington, D. C.: Government Printing Office, 1968). Also Oliver E. Williamson, "The Economics of Defense Contracting: Incentives and Performance," in Issues in Defense Economics, ed. by McKean, pp. 217-240.

[41] James R. Schlesinger, "Discussion of Defense Economics: Applying Economic Criteria," American Economic Review, May, 1965, p. 434.

Despite these limitations, however, there is certainly room for the application of improved economic and statistical analysis in a defense budget now affecting more than 50 percent of the federal government's total budget disbursements and 8 to 10 percent of the country's gross national product.[42] It has been pointed out that there are four distinct stages in the input-output sequence related to national defense: (1) the cost to the economy of raising, equipping and supporting the forces involved; (2) the deployment of these forces; (3) the success of the forces in achieving military objectives; and (4) the social utility of these military successes to the nation.[43] Economic analysis has in the past been primarily focused on (2) and (3), leaving (1) and (4) to the political process. This study, however, investigates economics involved in support aspects at the first stage. Such analyses, which assume capability decisions "given" at higher levels, may be called "sub-optimizations" and correspond to the

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[42] See U. S., Bureau of the Budget, The Budget of the United States Government for Fiscal Year 1970 (Washington, D. C.: Government Printing Office, 1969), p. 6 for information on total federal budget disbursements. See William A. Niskanen, "The Defense Resource Allocation Process," in Defense Management, ed. by Enke, p. 4 for a statement on defense budgets as a percent of gross national product.

[43] Richard N. Cooper, "Comments on Applying Economic Concepts to Defense Problems," in Issues in Defense Economics, ed. by McKean, p. 51.

partial equilibrium analyses of conventional economic theory. Such sub-optimizations are often both necessary and inevitable.[44] Chapter III deals in greater detail with the application of economic principles to ILSP including a discussion of problems which can arise as a result of sub-optimization.

Sequence of Presentation

Chapter I has contained introductory material including information on need for the study, its objectives, hypotheses investigated, research methodology followed, and scope and limitations of the study.

Chapter II deals primarily with background material relating to the study including the Department of Defense organizational framework for analytical decision-making; the concept of "logistics;" the scope, development and current status of Integrated Logistic Support Planning, particularly in the Navy; and a discussion of the challenge for the future which ILSP presents.

Chapter III discusses the efficient allocation of resources in Integrated Logistic Support trade-off situations, making use of theoretical indifference curve analysis and considering the techniques of elementary differential calculus in situations involving several

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[44] Hitch and McKean, The Economics of Defense in the Nuclear Age, pp. 129-130.

valuable inputs and one valuable output.

Chapter IV investigates the potential for use of Bayesian statistical decision theory in the ILS setting. The theory of Bayesian analysis is discussed together with its hypothetical application in actual equipment procurements.

Chapter V is concerned again with the meaning of the term "logistics" and considers in particular the material aspects of the elements which, by definition, make up ILS. Attention is given to such matters as calculation of the costs of holding inventory and the influence of customer service level (CSL) in determining the range and quantity of inventory carried.

Chapter VI discusses the meaning and use of cost-benefit and cost-effectiveness analyses in the ILS planning process. Contrasts are made with the use of these techniques in other branches of government and conclusions are reached pertaining to the usefulness of these methods.

Chapter VII is an integrative chapter, and indicates how the various tools and procedures that have been discussed could be brought together in one particular case.

Chapter VIII is entitled "Summary and Conclusions" and reviews the major findings of the study and conclusions reached. Certain recommendations for modifications in current logistic procedures are also made as a result of these findings and conclusions.

II

INTEGRATED LOGISTICS SUPPORT AND DECISION-MAKING IN THE DEPARTMENT OF DEFENSE

> "Sound logistic planning is the prime requisite of good weapon system support."[1]

Planning-Programming-Budgeting System

In 1961, having made defense operations a major issue in the preceding election campaign, President Kennedy appointed Robert McNamara as Secretary of Defense and Charles J. Hitch as Defense Controller.[2] Shortly thereafter a new method of military program control was adopted which had previously been suggested by a group of RAND economists.[3] This control involved a change from management concentration on individual military service activities to alloca-

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[1]R. A. Rodriquez, Qualitative Support Requirements (QSR): A Concept for Improved Logistics Support Planning During Weapon-System Development (Santa Monica, Calif.: The RAND Corporation, September, 1962), p. v.

[2]Niskanen, "The Defense Resource Allocation Process," p. 7 discusses in some detail the background surrounding these appointments.

[3]For example, see Hitch and McKean, The Economics of Defense in the Nuclear Age. Also David Novick, Efficiency and Economy in Government Through New Budgeting and Accounting Procedures and A New Approach to the Military Budget (Santa Monica, Calif.: The RAND Corporation, 1954).

tion of resources among major missions, with the services competing for these missions. A five year planning period was also established with the intention of making long-range implications of budget year decisions more visible. This technique of concentrating on mission, or program-oriented activities in resource allocation became known as the Planning-Programming-Budgeting System (PPBS). So successful did the PPBS system appear that its extension to all federal agencies was ordered by President Johnson in 1965.[4] The PPBS system is important for ILS because logistics support requirements appear in the DOD five year plan together with acquisition of the weapon system which is to be supported. It is therefore the responsibility of logisticians to determine these requirements as accurately as possible.

The fundamentals of the Department of Defense PPBS System are as follows:[5]

1. The program is a formal one. It is written, organized into specific categories and prepared at least five years ahead.
2. The program is comprehensive in that it is designed to show

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[4]John F. Due, Government Finance: Economics of the Public Sector (4th ed.; Homewood, Ill.: Richard D. Irwin, Inc., 1968), p. 60.

[5]These points are based on information contained in U.S., Department of Defense, A Primer on Project Prime (Washington, D.C.: Office of the Secretary of Defense (Controller), November, 1966).

the full cost of the total enterprise for each of five years.

3. Inputs to the program in terms of men, money and material are stated as well as outputs and the two are related. Thus, the resources necessary to complete the stated objective are clearly shown.
4. The approved program represents management decisions among alternatives available.
5. The program is the primary tool to be used in Defense Department management planning and decision-making. It is the nucleus for the whole defense management and control process.
6. A procedure is provided within the structure of the system for making changes. Hence the program is theoretically always kept current and up-to-date.

Accompanying implementation of the PPBS concept was the adoption of various quantitative techniques designed to aid the decision-maker in the process of selecting from among a number of competing alternatives. Among these techniques are such procedures as cost-benefit analysis, cost-effectiveness analysis, and systems analysis.[6] Better utilization of government resources is stressed through defense management consideration of possible trade-offs

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[6]These analytical techniques are defined and discussed in some detail as they relate to ILS in Chapter VI, infra.

among alternatives. In the first full-fledged use of these techniques in 1962, however, it is perhaps significant that Department of Defense analysts rejected nearly all program change requests to the recently established five year plan. Since that time, ". . . unfortunately, the analytic process has often been associated with the refutation of service arguments rather than with the initiation and channeling of continued change."[7] Indeed, a criticism often made of the PPBS system is that it tends to centralize decision-making in the Secretary of Defense and his staff to the detriment of innovation.[8]

Implications of centralized decision-making for ILS. -- Whether this centralization, requiring top-level approval of many defense resource allocation decisions, has proved beneficial seems largely a matter of opinion. One observer has discussed both sides of the controversy as follows:

> The centralization of political decisions regarding the total defense budget and its allocation among missions is the key element of the present decision process and is probably necessary for effective civilian control of the U.S. military establishment. But the centralization of the management decisions regarding the allocation of resources within each mission area is a matter of style. . . . increased centralization of defense management may

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[7]Niskanen, "The Defense Resource Allocation Process," p. 10.

[8]Due, Government Finance: Economics of the Public Sector, p. 61.

> already be having a detrimental effect upon national security interests.[9]

Another writer on the subject points out that centralization of military decision-making is to a large degree necessary and that steps in the direction of more decentralization must be taken with care. Specifically, he states that:

> In its most important characteristics...the defense establishment must be a centralized organization, and decentralization must proceed cautiously if it is to produce beneficial rather than harmful results...a certain amount of direct supervision of the choice between weapons systems and of the provision for their development, support and reserve supplies is necessary for the pursuit of a rational set of national objectives.[10]

In any event, the centralized PPBS System, including procedural changes made to date, forms the structure within which the Integrated Logistics Support (ILS) program must function. Major program-oriented missions are ultimately centrally approved or disapproved on the basis of a systematic comparison of the respective cost and effectiveness of alternative feasible methods of accomplishing the mission. Costs are aggregated by missions so that political choices can be made concerning the allocation of resources among these missions, leaving management choices for within-mission

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[9] Niskanen, "The Defense Allocation Process," p. 18.

[10] Martin J. Bailey, "Defense Centralization Through Internal Prices," in Defense Management, ed. by Enke, p. 342.

allocation. These are the choices with which this study is concerned. The aim of ILS is to establish a procedure whereby the support costs of weapon systems and equipment can be made more visible, related to total system costs and a support plan developed which can be "sold" to decision-makers on economic grounds. With this general background the concept and meaning of the term "logistics" can now be examined more closely, with special attention being given to its relevance for ILS planning.

The Concept of "Logistics"

Logistics in the military sense is officially defined as "The science of planning and carrying out the movement and maintenance of forces. In its more comprehensive sense, [logistics includes] those aspects of military operations which deal with: (1) design and development, acquisition, storage, movement, distribution, maintenance, evacuation, and disposition of material; (2) movement, evacuation, and hospitalization of personnel; (3) acquisition or construction, maintenance, operation and disposition of facilities; and (4) acquisition or furnishing of services."[11] Logistics, tactics and strategics are generally considered the three main divisions of

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[11]U.S., Joint Chiefs of Staff, Dictionary of United States Military Terms for Joint Usage (Washington, D.C.: Government Printing Office, 1968), p. 126.

military responsibility. One writer has succinctly referred to the role of the logistician within this division of effort in stating: "...the military services have the logisticians who support both strategy and tactics, being responsible for getting the military hardware and supplies to the right places at the right time to do the job."[12] Finally, Eccles has summed up well the meaning of military logistics in his statement that it is "...the process of planning for and providing goods and services for the support of the military forces."[13]

Business and economics usage. -- This study primarily limits itself to those management aspects of items (1), (3) and (4) above which deal with military functions somewhat analogous to those found in business, and especially to the area of material support. In this context, the American Marketing Association has defined logistics as all activities involved in "The movement and handling of goods from the point of production to the point of consumption or use."[14] In more general economic terms, it may be said that

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[12] Richard S. Denenholz, "Physical Distribution as a New Staff Function in Marketing," in The Frontier of Marketing Thought & Science, ed. by Frank M. Bass (Chicago: American Marketing Association, 1957), pp. 96-97.

[13] Henry E. Eccles, Logistics in the National Defense (Harrisburg, Penna.: The Stackpole Company, 1959), p. 45.

[14] Definitions Committee of the American Marketing Association, "1948 Report," The Journal of Marketing, Oct., 1948, p. 202.

logistics concerns "the translation of consumer demand for time and place utility into a supply of these same kinds of utility."[15] Time utility is created primarily by transportation and distribution. Place utility is created by acquiring and holding inventory and by insuring ready availability of goods and services. This material support aspect, the ability to adequately satisfy consumer demand through providing time and place utility, is a primary focus of this study.[16]

Logistics in the Navy. -- In relating this general concept of logistics to the naval establishment, Dyer distinguishes between the categories of "Consumer Logistics" and "Producer Logistics" in the following manner:

> Consumer logistics is concerned with the determination and distribution of the requirements of the Operating Forces for material, services, and personnel. This aspect of logistics is carried on at the national and departmental levels. An example of this is in the determination by the Chief of Naval Operations of the type and quantity of naval aircraft required by the Operating Forces.

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[15] J. S. Heskett, Robert M. Ivie, and Nickolas A. Glaskowsky, Jr., Business Logistics: Management of Physical Supply and Distribution (New York: The Ronald Press Company, 1964), p. 8.

[16] Ibid., pp. 20-21, points out that while there are important differences between logistics as viewed by the military and by business, there are also similarities, particularly in the area of movement and storage of products and supplies. "Business logistics" is defined by these authors as "the management of all activities which facilitate movement and the coordination of supply and demand in the creation of time and place utility in goods."

> Producer logistics is concerned, in very general terms, with the procurement of those requirements of the Operating Forces as determined by the Chief of Naval Operations. As in the case of consumer logistics, this aspect is carried on at the national and departmental levels. An example of producer logistics is the procurement at the Bureau level of the naval aircraft the Chief of Naval Operations determined were required by the Operating Forces.

Having made this distinction, he then concludes that consumer logistics in the naval establishment is primarily the responsibility of command, whereas producer logistics is a "business administrative task."[17]

Within the Navy, as may be noted from Appendix B, the Chief of Naval Operations (CNO) is responsible for management of the logistics function. He is "responsible for over-all direction of the Navy's material programs and the stating of material requirements in general terms, taking into consideration the constraints of Navy and DOD-approved force levels and budgeting limitations contained in the Five-Year Defense Program (FYDP)."[18] All Navy material requirements therefore derive from guidance and policy handed down by the CNO. Under the CNO, the Chief of Naval Material (CNM) and his organization have responsibility for equipment support. The Commander, Naval Supply Systems Command, in turn, is responsible

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[17] George C. Dyer, Naval Logistics (3rd ed.; Annapolis, Md.: United States Naval Institute, 1962), pp. 11-12.

[18] Department of Defense, Supplying the Navy, p. 9.

for "business and supply judgments and techniques"[19] and for the procurement of about $13 billion worth of goods and services annually.[20] He is also designated the "Manager of Navy Material Transportation" and as such is responsible for efficient management of the movement of Navy freight.[21] These are main links in the logistics support chain with which this study deals.

Considerations in Naval Integrated Logistic Support Planning

In Chapter I it was pointed out that speed of design, production and delivery characterized much of the military weapon system and equipment acquisition process during the late 1950's and early 1960's and that this requirement was often detrimental to related quality and cost considerations. This sacrifice of cost and quality in favor of speed, however, eventually caused concern to be evidenced for the resultant readiness or "availability" of affected weapon systems and equipment.

The inherent availability of a weapon system or equipment depends in turn upon the engineering concepts of reliability and

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[19] Ibid., p. 16.

[20] Shillito, "Assistant SECNAV Shillito Speaks on the Corps," p. 14.

[21] Department of Defense, Supplying the Navy, p. 36. See also the discussion in Chapter I, supra.

maintainability. Reliability has been defined as the quantifiable probability that specific equipment will continue to function correctly for a specified period of time without failure under a prescribed condition of use. Maintainability is similarly defined as the quantifiable probability of equipment being restored to operating status within allowable time limits using available test equipment, facilities, personnel, spare parts and procedures.[22]

Concept of Availability. -- The most frequently used measure of reliability is the statistical concept of mean-time-between-failure (MTBF) and that of maintainability, mean-time-to-repair (MTTR).[23] Using these measures, inherent availability of a weapon system may be expressed by the equation:

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} \; .$$

For a weapon system to be useful, it must be available, that is it must not only be delivered expeditiously, but also must be able to perform under expected operating conditions and in the intended maintenance environment. Supportability as well as performance,

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[22] U.S., Department of Defense, Publication 4100.35-G, Integrated Logistics Support Planning Guide for DOD Systems and Equipment (Washington, D. C.: Government Printing Office, 1968), p. 37.

[23] Giordano, "Logistical Implications of Weapon System Design Decisions," p. 195.

therefore, is an important consideration. It has frequently been noted, however, that "Unfortunately, we have far too many examples of too much emphasis on performance and too little on support of... a system."[24] It has also been pointed out, for example, that in the specific area of naval ordnance development, as systems grow more complex, interrelationship problems tend to become compounded causing even greater problems of logistics support.[25] One writer, referring to the operational problems resulting from this increased system complexity, states:

> Reports from the Fleet have stressed that weapon systems and equipments, because of their complexity are becoming more difficult to operate and maintain. Also, it has be reported that repairs have been delayed by lack of trained personnel, the non-receipt of technical documentation, and the non-availability of repair parts and spares.[26]

The increasing importance of logistics support considerations. -- In addition to speed of delivery, performance and supportability factors, the increasing sophistication of modern weapon systems has also acted to render it imperative that support factors be more fully considered. In the first place, serious problems of

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[24] Frank N. Worden, "Integrated Logistics Support," Navy Supply Corps Newsletter, June, 1965, p. 21.

[25] Miles H. Hubbard, "The Design of Naval Weapons," United States Naval Institute Proceedings, October, 1965, p. 41.

[26] Shaughnessy, A Preliminary Review of DOD Directive 4100.35 of June 19, 1964, p. 8.

cost estimation have developed. One study for instance, reported that of twelve major defense programs studied, development cost turned out to be as much as seven times original estimates with an average variance of about 220 percent.[27] Another problem is that system costs often were not considered in total. A weapon system, cost-wise, is actually composed of two primary elements -- acquisition costs and ownership costs.[28] These latter costs were often overlooked, ignoring the significant point that "maintenance and operating costs, for the most part, far exceed development and investment costs."[29] From a cost-effectiveness standpoint, an optimum allocation of resources was frequently not being achieved.[30]

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[27]Merton J. Peck and Frederic M. Scherer, The Weapons Acquisition Process: An Economic Analysis (Boston: Division of Research, Graduate School of Business Administration, Harvard University, 1962), p. 429. Development Cost Factors (actual cost ÷ original cost estimate) were calculated for each program, and an average Development Cost Factor obtained as the arithmetic mean. The variance was then derived from this average, with 1.0 of the factor representing the original estimate, and the remainder the variance.

[28]A. D. Davies and E. J. Shaughnessy, The Logistician in Integrated Logistics Support (Washington, D. C.: Planning Research Corporation, June, 1965), p. 8.

[29]George E. Fouch, "Integrated Logistic Support - What the Customer Expects," speech before the National Security Industrial Association Meeting, Washington, D. C., October 7, 1968.

[30]See Chapter VI, infra, for a more detailed discussion of the technique of cost-effectiveness analysis. For now it is sufficient to state that the term involves a determination that the effectiveness to be gained is worth the cost involved in attaining the gain. See also

A major contributing factor to this situation was the fact that basic military procurement practices had not been changed since prior to World War II. Price of initial acquisition was still the prime consideration despite a legal requirement that "award shall be made... to the responsible bidder whose bid... will be most advantageous to the United States, price and other factors considered (author's italics)."[31] These "other factors" are essentially logistics costs but were seldom systematically evaluated. Concerned about this, the Assistant Secretary of Defense (Installations and Logistics) in 1963 directed that a study be made of the economic consequences of taking only initial price acquisition into active consideration in contract awards.[32] A conclusion of this study was that logistics costs as well as purchase price can vary significantly among different bidders, and that these costs can be measured and should be taken into consideration in awarding development contracts.

As a result of these developments, and intending to make use of the techniques of quantitative analysis brought into wider use after

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Giordano, "Logistical Implications of Weapon System Design Decisions," p. 196.

[31]Section 2305(c), Title 10, U.S.C.

[32]Logistics Management Institute, Life Cycle Costing in Equipment Procurement (Washington, D.C.: Logistics Management Institute, April, 1965) contains the resultant report.

1961, the Department of Defense, as mentioned in Chapter I, introduced in 1964 the concept of Integrated Logistic Support Planning. DOD Directive 4100.5 formally defined ILS as "A composite of the elements necessary to assure the effective and economical support of a system or equipment at all levels of maintenance for its programmed life cycle. . . . " The elements initially listed as comprising ILS were:

1. Planned Maintenance
2. Support Personnel
3. Technical Data and Publications
4. Support Equipment
5. Spares and Repair Parts
6. Facilities
7. Contract Maintenance

Implementing directives establishing ILS were subsequently issued by the Department of the Navy.[33] The ILS concept as developed in these directives has essentially three prime purposes as relates to resource allocation:

1. To insure that all the designated elements of support are identified and provided for early in the hardware development cycle so as to be ready when needed.

2. To insure that a piece of shipboard hardware is capable of

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[33]Department of the Navy, SECNAV Instruction 4000.29, Development of Integrated Logistic Support for Systems and Equipment implemented the application of the concept within the Navy; and Department of the Navy, NAVMAT Instruction 4000.20, Integrated Logistic Support Planning Procedures promulgated working procedures.

being maintained by the people on board and reliable enough to meet operational requirements.

3. To consider possible cost and/or performance trade-offs early in the development of a weapon system and its support hardware.

The basic principles of this new concept of Integrated Logistics Support as formulated by the Secretary of the Navy are listed in detail in Appendix D.

Concept of life cycle costing. -- Integrated Logistics Support has been aptly called the "life-cycle" task of support management.[34] This implies that the process of logistics planning should begin with initial design of the weapon system since this design will certainly significantly influence the magnitude and type of logistics support thereafter required.[35] Logistic planning which begins after design of the weapon system has been completed can ultimately be highly expensive. Early interface between the design engineer and the logistician is thus recognized as being essential. In the implementing DOD directives, the Acquisition

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[34]For an example of the use of this terminology, see Gerald Holsclaw and Fred T. Carlson, "Integrated Logistic Support: The Life-Cycle Task of Support Management," Defense Industry Bulletin, June, 1968, p. 1.

[35]Logistics Management Institute, Methods for Evaluating the Cost/Effectiveness of Alternate Support Plans for Major Weapon Systems, p. 7.

Manager is made responsible for establishing such relationships and agreements within the Defense Establishment as will enable him to properly carry out his tasks. These directives recognize that the ILS concept requires that all decisions made in initial design and development shall take into account accompanying logistic implications.

From a procurement and operation standpoint, the life cycle of a major weapon system or equipment goes through several phases important for ILS planning. These are: concept formulation, contract definition, development, production and operation. Support activities which are designed to take place during these phases are summarized in Appendix G. Appendix H shows in a different perspective these life cycle phases in relationship to over-all equipment design considerations. This relationship indicates that it is important for both operational design and support design factors to be taken into account as early in the equipment life cycle as possible in order that any desired changes can be made prior to entering into actual hardware production, beyond which point changes become much more costly. Continual review and improvement of logistic support aspects is therefore essential, considering the over-all impact on system objectives involved including system performance and availability. In carrying out this task, the Acquisition Manager and logisticians should have an appreciation for the techniques developed and discussed in this study.

From a logistics viewpoint, the concept of life cycle costing essentially involves the development of a new method of military procurement. By following this concept another alternative can be made available in addition to the methods of sole source or price competition previously used, namely, competition on the basis of total cost rather than bid price alone. This is particularly important since that portion of the DOD budget devoted to logistics (including procurement of spares and repair parts) exceeds in cost that devoted to the acquisition of systems and equipment.[36] For many DOD procurements, consideration of the economic aspects of acquisition costs alone means that many potentially significant cost differences inherent in competing bids are ignored. Table II-1 demonstrates the importance of this point showing a hypothetical example of how a contractor with the low initial bid might not be the ultimate low bidder when all costs involved in his approach are considered. In compiling figures such as indicated in Table II-1, the use of estimated logistics costs, despite their uncertainty, is usually preferable to completely ignoring them as has often been done in the past.

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[36] L. B. Early, S. M. Barro, and M. A. Margolis, Procedures for Estimating Electronic Equipment Costs (Santa Monica, Calif.: The RAND Corporation, May, 1963), pp. 19-20, 22.

TABLE II-1

HYPOTHETICAL EVALUATION OF TOTAL COSTS

ASSOCIATED WITH DIFFERENT CONTRACTOR

BIDS FOR A WEAPON SYSTEM

(in Dollars)

Cost Elements	Contractors		
	A	B	C
Bid Price	41,000	60,000	45,000
Maintenance contract	130,000	122,000	86,000
Test equipment	10,000	20,000	10,000
Inventory support	47,000	32,000	43,000
Transportation	8,000	7,000	6,000
Handling	2,500	2,300	2,100
Facilities	15,000	10,000	10,000
Training	8,000	8,000	8,000
Documentation	12,000	16,500	12,000
Totals	273,000	277,800	222,100

Contractor "A" has the lowest bid price, but Contractor "C" is low bidder when all resultant elements of cost are considered.

Scope of Integrated Logistics Support. -- A problem has also arisen in arriving at a final determination of the elements which should comprise ILS, and the specific ground each element should cover. An Ad Hoc Committee with DOD, military service and industry representation carried out a study pertaining to the possibilities for implementation of ILS and reported that:

> There is a need to scrutinize the elements of integrated logistic support listed in DOD Directive 4100. 35 to determine whether they truly constitute a well-defined package. Three problem areas revealed in the task reports dictate that such an examination be conducted. These problems are:
> 1. Lack of definition of what elements truly constitute an integrated logistic support package.
> 2. Lack of uniformity in element definition and nomenclature.
> 3. Lack of uniformity in element grouping for cost purposes.[37]

This problem is investigated further in Chapter V. For now it should be noted that as one consequence of the Ad Hoc Committee Report, the Department of Defense subsequently issued Publication 4100. 35-G which revised the original definition of ILS so that it now includes the following ten items:

1. Maintainability and Reliability
2. Maintenance Planning
3. Support and Test Equipment

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[37] U. S., Department of Defense, Report of DOD Directive 4100. 35 AD HOC Committee, Vol. I: Introduction (Washington, D. C.: Office of the Secretary of Defense, August, 1965), p. 10.

4. Supply Support
5. Transportation and Handling
6. Technical Data
7. Facilities
8. Personnel and Training
9. Funding
10. Management Data

The scope included in the meanings of these elements is summarized in Appendix E. That these elements can by no means be considered a final compilation, however, can be inferred from the statement of one observer that "It is obvious that industry and other Military Services have different peculiar elements that comprise a specific routine. Nevertheless, ILS has identified 10 essential support elements which should be managed in relationship to a hardware program."[38]

<u>The role of support management.</u> -- An important point in the preceding discussion is that the life cycle cost of military systems and equipment has now been recognized as involving "the total cost incurred by the Government from the moment the investigation of its generating idea elicits manpower usage within or without the Government until every piece of the equipment is eliminated from the military logistics system."[39] The function of support management is thus

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[38] George C. Axtell, "Designing an Integrated Logistics System," <u>Defense Industry Bulletin</u>, July, 1969, p. 32.

[39] Logistics Management Institute, <u>Life Cycle Costing in Equipment Procurement</u>, p. 2.

now considered to be as important as those of production management, system design, or administration and control. Appendix F depicts the ten ILS management functions in relation to other typical functions of project management of a weapon system or major equipment program. The interrelationships apparent in this chart demonstrate that a project manager cannot concentrate on one group of these functions to the exclusion of the others.

In view of this, it is obviously essential that persons charged with logistic responsibilities be thoroughly grounded in such technical, administrative and theoretical skills as will enable them to properly carry out their assignments. The Acquisition Manager must be much more than simply a highly competent engineer. As for the logistician assigned to the Acquisition Manager, he also must possess particular skills that have not necessarily been previously required in combination in a military situation. Concerning the logistic aspects of system acquisitions, it is now necessary for responsible persons to be able to:

1. Define in precise terms the quantitative and qualitative logistic support requirements of the system.
2. Predict logistic support costs in terms of resources and funds.
3. Conduct necessary systematic analyses, evaluations, and trade-off studies.

The focus of this study deals with what might be called "logistic support cost-effectiveness." Logistics Management Institute (LMI) has defined this term as referring to "...the cost and the capability or the effectiveness of the logistic support system in bringing a weapon to a condition in which it is ready to operate according to its assigned mission."[40] The term also necessarily implies the ability of the logistics support system to insure continuing availability of the equipment.

Element managers. -- Also of importance in the logistics chain under discussion are the Navy "element managers," i.e., those members of organizational entities officially responsible for management of the ten designated ILS elements. Particularly important responsibilities in this regard rest on the Commander, Naval Supply Systems Command (NAVSUP), Commander Naval Facilities Engineering Command (NAVFAC), and the Chief, Bureau of Naval Personnel (BUPERS).[41] The element managers participate in all logistic decisions made by an Acquisition Manager. NAVSUP,

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[40] Logistics Management Institute, The Cost/Effectiveness of Alternate Support Plans for Major Weapon Systems, p. 35.

[41] Department of the Navy, NAVMAT Instruction 4000.20, Integrated Logistic Support Planning Procedures, p. 5. See also Appendix B infra which shows where these organizations fit into the total Navy Support Structure.

NAVFAC, and BUPERS provide the input and make decisions on ILS matters relating to supply support and transporation, facilities, and personnel respectively.[42] The element managers are charged with ensuring the availability of resources in their areas of responsibility on a continuing basis throughout the entire ILS process. Logistic support actions must, of course, be "tailored" in each specific case to meet the particular needs of individual systems and equipment.

This study is especially concerned with the role of the Naval Supply Systems Command as an element manager in the ILS process. Having the right supplies when and where needed is extremely important for weapon system and equipment readiness or availability considerations. As previously noted, Supply Support is one of the ten ILS component elements now recognized by the Navy. This element in turn is composed of provisioning, distribution and inventory replenishment, and maintenance of spares, repair parts, and special supplies. Supply Support planning depends upon engineering estimates of such factors as system/equipment utilization rates, operating hours, failure rates, required field repair rates, locations, and selected maintenance items critical to safety and mission accomplishment.[43] This material management function is one that requires

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[42] Ibid., p. 10.

[43] Holsclaw and Carlson, "Integrated Logistic Support: The Life-Cycle Task of Support Management," p. 9.

constant attention throughout the equipment life cycle phases, as can be noted from Appendix G.

Transportation and Handling is another of the ten identified ILS elements which is the responsibility of NAVSUP. This element includes all actions incident to transporation, packaging and preservation of material. Specific activities involve the determination of:[44]

1. Transportability criteria including volume, frequency and security of shipments.

2. Desired locations for transporation and facilities.

3. Planned material availability by quantity, volume and location.

4. Special transporation and handling procurement requirements.

5. Interactions with the other ten ILS elements, and with operational design requirements.

In order to properly execute its responsibilities, logistics support management must: (1) have an appreciation for the mission system and equipment; (2) recognize and provide support resources throughout the system's life-cycle; (3) request and schedule funds as necessary to ensure support; (4) provide for continuing interaction between the Acquisition Manager, his logistician and all element managers; and (5) make use of such management concepts and techniques as will facilitate these activities. This study investigates

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[44] Ibid.

certain of these concepts and techniques. In military systems, the development and operation of teamwork among specialists in various fields, including the logistics disciplines, is required if resources are to be used in the most efficient manner. As weapon system Acquisition Managers are forced into more of a cradle-to-grave concern for operation of the system, they will necessarily come to rely more and more upon the advice of logistical specialists.

Challenge for the Future

From the preceding discussion of circumstances surrounding the development of ILS, it is apparent that the concept is basically designed to insure that responsible logistic personnel become involved early in the development phase of new weapon systems or equipment. Specifically, Navy directives implementing ILS require that:

1. The concepts involved apply to all acquisitions in the Navy, even though only major procurements go through the complete, formal life cycle process.[45]

2. The system Acquisition Manager is responsible for

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[45] Appendix C to NAVMAT Instruction 4000.20, Integrated Logistic Support Planning Procedures, for example, is entitled "An Integrated Logistic Support Planning Procedure for Acquisitions of Less Extensive Systems or Facilities Requiring a Design and Development Contract." Appendix D is entitled "An Integrated Logistic Support Planning Procedure for Acquisitions of Off-the-Shelf Military Standard or Commercial Equipments." These appendices provide guidelines for the acquisition of less than major systems.

implementation of ILS planning.

3. A logistician is assigned to the Acquisition Manager to assist in the planning.
4. ILS planning is supposed to start at the beginning of the acquisition process.
5. All logistic element managers are to participate in the planning process.

In theory this is a highly desirable and challenging concept. As one report puts it: "Given the goal of maximizing weapon and equipment readiness at optimum costs, the integration of logistic support elements into complementary time-phased and mission oriented actions is a management tool which today challenges all members of the defense team...military, civilian, and contractor alike."[46] Yet the system is not presently in full and complete operation. A writer on the subject recently stated that "...although Integrated Logistic Support Directive 4100.35 was issued more than 3 years ago, it has not been effectively implemented."[47]

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[46] Logistics Management Institute, DOD Systems and Equipment Integrated Logistics Support Planners Guide (Washington, D.C.: Logistics Management Institute, 1967), p. iii.

[47] J. Reed, "The DOD-CODSLA ILS Need/Use Report," Proceedings, Integrated Logistic Support Symposium (Washington, D.C.: Electronic Industries Association, March 7, 1968), p. 49.

Several problem areas which have delayed the implementation of ILS are, however, amenable to solution. For example, difficulties have come up in ascertaining the true dollar cost of "logistics support." Also, qualified logisticians do not yet exist in adequate numbers and there is no firmly established organizational framework within which the system can operate. Differences in interpretation and implementing action of the objectives of ILS exist at all organizational levels. In addition, the concept has not yet been carried out through the entire life cycle of a major system, so it has not been proven that expected benefits will in fact result. A start, however, has been made. As Giordano puts it: "...the Navy assault on the ILS learning curve beings."[48] In theory, ILS unifies previously independent logistic efforts.

The purpose of this study is to aid the logistician by increasing his knowledge and skills so that greater benefits may be realized in the future from Integrated Logistic Support Planning.

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[48]Giordano, "Logistical Implications of Weapon System Design Decisions," p. 203.

III

ECONOMIC ANALYSIS IN INTEGRATED LOGISTICS SUPPORT

> . . . the services are concerned primarily with the defense of the United States and not with saving the taxpayers' money.[1]

The purpose of this chapter is to demonstrate that certain relatively fundamental microeconomic and mathematical concepts and tools can serve as important aids in helping the logistician to effect more efficient allocation of resources in the Integrated Logistics Support environment.

Economic Principles of Resource Allocation

How to get more and how to make the best use of what is available has been described as "the economic problem, the ever-lasting problem of every family, every business firm, and of every government unit."[2] Implicit in this statement is the fact that resource

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[1] Alain Enthoven and Henry Rowen, "Defense Planning and Organization," in Public Finances: Needs, Sources, and Utilization, ed. by James M. Buchanan (Princeton, N. J. : Princeton University Press for the National Bureau of Economic Research, 1961), p. 381.

[2] Watson, Price Theory and Its Uses, p. 4.

limitations have become as much a fact of life in the military as in private business and this must be recognized by the defense planner as one of the major constraints he faces.

Economic theory is traditionally divided into two main groupings -- macroeconomics and microeconomics. The former deals with aggregates and is concerned with how these aggregates reach certain levels, and why changes occur. This may be called the "big picture," although it is composed of many individual elements. Microeconomics, also known as price theory, deals on the other hand with the elements comprising these aggregates. These two approaches are complementary rather than mutually exclusive. The microeconomic approach, however, is used in this study in that it provides a more convenient framework for analyzing components of military economic activity such as ILS. Some have alleged, in fact, that since the end of World War II the single most important application of microeconomic analysis has been in the area of national defense planning.[3]

The problem of sub-optimization. -- Microeconomic analysis is also particularly appropriate for use by military decision-makers because in this organizational structure the great majority of manage-

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[3]Watson, _Price Theory and Its Uses_, p. 11.

ment choices are ultimately made at lower levels.[4] At these lower levels the opportunity frequently presents itself to make use of quantitative analytical techniques since many of the broad, qualitative issues are centrally decided at higher levels in the government. Quantitative analysis is thus perhaps even more readily usable at the level of the ILS logistician than at comparable levels in the business firm. Such analysis, however, often requires the use of the technique of sub-optimization (see Chapter II in this regard). Under this procedure, management decisions are made in as near an optimal manner as possible, but at the level of the logistician rather than at the higher level of over-all national defense planning. Of course, higher level objectives cannot be overlooked by the logistician. In an analagous situation in a business enterprise, the marketing department, for example, is expected to carry out activities which will help to maximize profits of the firm as a whole. So it is with the military logistician and his organization.

The primary danger of sub-optimization at lower levels is that quantitative criteria selected for choosing among alternatives may turn out to be inconsistent with those used in making higher level qualitative decisions. The logistics decision-maker must therefore

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[4]Hitch and McKean, The Economics of Defense in the Nuclear Age, p. 127.

be on guard that in the process of choosing what appears to be an optimal course of action he does not adopt an overly parochial viewpoint and thereby compromise higher priority objectives. As an example, the Navy supply support element manager for ILS might have a decision to make concerning provision of a particular level of spare parts in inventory in support of a newly acquired weapon system. He could make a decision in such a fashion that operation of the Navy supply system would be "optimized," but the over-all capability of the total weapon system would be reduced through provision of too low a reserve stock of especially critical spare parts. This matter is given further consideration in Chapter V where aspects of Navy inventory control procedures are discussed.

The concept of trade-off. -- In Chapter I, economic efficiency was represented as involving a situation in which maximum possible benefits are realized from available resources. Since the funds designated for ILS are assumed given, it is then the task of the logistician to use these funds in the most efficient manner possible. An efficient position is one in which additional output of the good or service in question cannot be achieved except at sacrifice of the output of some other good or service. Efficiency, however, can also refer to the achievement of any time-quality result with minimum expenditure of resources regardless of whether the resultant choice is

optimal.[5] Choosing from among equally efficient combinations is called optimization. The term efficiency as used in this study involves consideration of how the choice of a particular alternative is arrived at and only consequently with how well managed a program may be. Since quantitative analysis is designed to arrive at an optimal position, it is necessary to be able to measure the value of physical inputs and outputs. Inputs can theoretically be measured in terms of units of cost, and output in terms of "military worth."[6] Given that such calculations can be made, the object then would be to maximize the military worth obtainable from a given level of expenditure (or sacrifice). As various feasible efficient choices are made, resources are shifted to obtain maximum military worth in the face of existing constraints. This sacrifice in one area to achieve gains in another is termed a "trade-off." Optimization of the allocation of resources to logistics support of a weapon system requires that trade-offs be made by logistics personnel aimed at maximizing military worth, given budgetary limitations and applicable time-quality constraints.

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[5] Frederic M. Scherer, The Weapons Acquisition Process: Economic Incentives (Boston: Division of Research, Graduate School of Business Administration, Harvard University, 1964), p. 4.

[6] In the military, resource cost is generally measured by book value. An alternative, more desirable method involves use of the concept of opportunity cost discussed *infra*.

The concept of trade-off is very important in the ILS process and some specific examples are discussed below. Assuming for the moment, however, that the best possible trade-off among logistic support element inputs has been reached, the economic theory of marginalism can be brought to bear to demonstrate that the optimum capability achievable from a weapon system is at the point where marginal value received from reaching a level of capability is equal to the marginal cost incurred.[7] This concept of marginalism is of particular importance in view of the fact that logistic support elements form such a significant portion of total system costs.

To demonstrate the principle involved, assume that it is desired to maximize the military worth of a particular weapon system. Assume also that it is possible to estimate the value to the nation of this weapon system through the combined use of quantitative analytic techniques and qualitative judgment at appropriate levels in the de-

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[7]In actual practice, however, the planned level of weapon system capability might be set below that obtainable because of budgetary or political reasons, or because the additional capability might not be considered essential in the near future. Managers in the public sector must bear such limitations in mind. While admittedly not subject to the profit motive, these managers are subject to other pressures to perform. They seek to obtain and keep positions of responsibility and hence desire to maximize the value of services performed. It would be difficult to demonstrate that these pressures are less intense than those in the private sector. For a further discussion of this point see Due, Government Finance: Economics of the Public Sector, pp. 148-153.

cision hierarchy. Let W then represent military worth, A the capability "output," C the total cost of producing the output, and N the value received from achieving the output. We define W as $W = N - C$, and assume that N, C, and hence W are functionally dependent on A. Using the terminology of differential calculus, it can be stated that when the first derivative of W with respect to A is zero, W is at a maximum.[8] Thus, differentiating W and setting the derivative to zero, we arrive at

$$\frac{dW}{dA} = \frac{dN}{dA} - \frac{dC}{dA} = 0.$$

The output level which maximizes W can then be characterized by the condition

$$\frac{dN}{dA} = \frac{dC}{dA} \ .$$

Now the first derivative of N with respect to A, $\frac{dN}{dA}$, may be called marginal value, and, in like manner, $\frac{dC}{dA}$, may be called marginal

[8]Sufficient to insure that the maximum will be characterized by the condition $dW/dA = 0$ is that W be concave and twice differentiable over the range of relevant values of A, say $0 \leq A \leq \infty$, and that the maximum occurs at some value A^*, such that $0 < A^* < \infty$. Stated simply, this means that as A increases from zero to infinity, W rises smoothly to its maximum and then declines smoothly from its maximum.

cost. Military worth, W, is thus maximized when marginal value received equals marginal cost. The military logistician must attempt to allocate his resources so as to approach this theoretical ideal.

The foregoing has perhaps conveyed the impression that an estimate of military worth of particular systems is fairly straightforward. It is not. The value of the entire military establishment in peacetime can perhaps be most accurately measured in terms of the destruction which, because of its existence, it prevents. Direct measurement of any one individual system within the total structure is, however, extremely difficult to do with any real precision. Yet, as some writers have noted, "...military value judgments must and indeed are being made, either explicitly or implicitly, by military planners."[9] The important point, then, is that these calculations be made as accurately as possible with full realization of subjective factors inherent in the final judgment. Some of the quantitative methods used in making these calculations are discussed further in Chapter VI.

Considering only feasible alternatives and relevant costs. -- In calculating the costs of various alternatives, it is important to consider only such alternatives as are actually feasible. Thus a

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[9] Peck and Scherer: The Weapons Acquisition Process: An Economic Analysis, p. 273, italics added.

logistician might initially conclude that it would be more efficient to use certain technicians to perform a particular task rather than a very costly, highly sophisticated piece of machinery. Yet these technicians might not be available for assignment to this task and hence the choice is not feasible. An important job of the ILS element managers thus should be to advise ILS logisticians closely as to feasible alternatives. As yet, there is relatively little dialogue between these groups on this important subject.

Then, too, it is important to consider only the relevant costs of various alternatives. Future costs and values are of importance for decision-making. Costs that are "sunk," i.e., those that have already been incurred, or those that will be incurred regardless of the decision made should generally be ignored in making a choice among alternatives. Thus if a particular piece of equipment is now available and has no possibility of alternative use or no scrap value, then the capital cost of incorporating it into inventory to support a weapon system is zero. Incremental or marginal cost involved must be considered as the important concept in a choice.

A businessman in the private sector of the economy operates under similar circumstances. When faced with the necessity of making a choice as to whether he should buy a new machine or keep an old one, he must consider the total purchase price of the new

machine. Only the salvage or alternate use value, if any, of the old machine, however, enters into the calculation. The true cost of the new machine can be considered as being represented by the value of those alternatives which, because of the purchase, can now no longer be considered. This is the economic concept of alternative or opportunity cost. The longer the planning period involved, the higher this cost should tend to be, since additional feasible opportunities will probably present themselves over a longer time span.

It is important to note in this connection that all alternatives which have identical uses should be considered as having the same alternative or opportunity cost regardless of any difference in their historical costs.[10] The true cost to the economy of resources used in logistics support is the product thereby foregone in other public or private uses. Economics is, in fact, concerned with the problem of choices that become necessary because a good can be used in alternative ways and because these goods are scarce relative to potential demands for them.

It is true, however, that the determination of realistic costs on an alternative use basis can be quite difficult. What, however, is particularly important for the ILS logistician is that gross errors be

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[10]George J. Stigler, The Theory of Price (3rd ed.: New York: The Macmillan Company, 1966), p. 106.

avoided, such as treating those resources as "free" which, although previously paid for, still have valuable alternative uses. Truly relevant costs should not be excluded from any calculation leading to the making of a choice among alternatives. Ownership costs of a weapon system must thus be considered as well as acquisition costs. In the examples presented in this study, it is assumed that alternative cost measures have been employed.

As one example of the concept of alternative cost in the area of Integrated Logistics Support, consider a problem involving the necessity to value the worth of military personnel who will be required to support a system once it has been acquired. The wage rates of these personnel are set by Congressional action, but the real cost to the economy is the value of the product or service they will not be producing in the private sector. Similarly, material held in inventory for logistic support of a weapon system may also have valuable alternative uses. Such possibilities should be born in mind by the logistician.

<u>Discounting of future costs and benefits.</u> -- Also of importance in any economic calculation is the fact that future costs and benefits should be discounted to present value. Expected cost streams determined to be required in support of a particular alternative should be calculated as closely as possible and then discounted. These dis-

counted values essentially recognize the fact that a sum of money to be spent in the future or a benefit to be realized at some later time has a lower "present value" than the same sum or benefit spent or realized today. Thus the present value of an asset can be found in the following manner:

> The way to arrive at any asset's present discounted value is straightforward. Let each dollar stand on its own feet; evaluate the present worth of each part of a stream of future receipts, giving due allowance for the discounting required by its payment date. Then simply add together all the separate present discounted values. Thus we have arrived at the asset's capitalized market value, or what is called its "present discounted value."[11]

Financial institutions serving both the private and public sectors recognize the necessity for discounting at least in part through the means of receipt and payment of interest. If an expenditure can be delayed or avoided entirely, then the sum involved is available for alternative uses. The formula commonly used in computing present value is of the form:

$$\text{P. V.} = M \frac{1}{(1 + i)^n}$$

where: P. V. = The present value of a future expenditure or benefit.

M = The face amount of the future expenditure or benefit.

i = The applicable rate of interest to be used.

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[11]Samuelson, <u>Economics</u>, p. 587.

n = The number of years from the present to the time of expenditure or receipt of benefit

Present value tables have been computed using this formula for various values of i and n and are widely available.[12]

Until very recently the Department of Defense has directed that 4 percent be used as the rate for discounting purposes in problems of inventory management. This matter is discussed further in Chapter V. Here it should be noted, however, that a comparison of undiscounted cost or benefit streams, although the same in total, can often lead to erroneous conclusions. Table III-1 illustrates this point, listing both discounted and undiscounted cost streams of three alternatives being compared.

Cost Stream C, when discounted at 4 percent, is the preferable alternative in terms of present value of expenditures. This can be seen to be due to the $600 expenditure which is not required until Year five and hence has a relatively low discounted value.

Subtracting the present value of expenditures from the present value of receipts or benefits for competing alternatives leaves "net present value" figures which can then be compared. In doing this, of

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[12]For example, see the tables in Pearson Hunt, Charles M. Williams, and Gordon Donaldson, Basic Business Finance: Text and Cases (3rd ed.; Homewood, Ill.: Richard D. Irwin, Inc., 1966), pp. 984-985.

TABLE III-1

COMPARISON OF COST STREAMS UNDISCOUNTED AND DISCOUNTED AT 4 PERCENT

(in Dollars)

Year	Undiscounted Alternatives			Alternatives Discounted at 4 Percent		
	A	B	C	A	B	C
1	200	600	100	200	600	100
2	200	100	100	192	96	96
3	200	100	100	185	92	92
4	200	100	100	178	89	89
5	200	100	600	171	85	513
Totals	1,000	1,000	1,000	926	962	890

course, it must be borne in mind that resources are consumed in performing such cost analyses. The procedure should not, therefore, be carried beyond the point of economic advantage.

The Use of Microeconomic Theory

Economic analysis in Integrated Logistics Support can help in making choices among alternative combinations of resource inputs. Such an analysis can be broken down into a series of steps.[13] The

[13] In this connection, see the discussion in Hitch and McKean, The Economics of Defense in the Nuclear Age, pp. 118-120, for a general discussion of the elements of a problem of economic choice in the military.

first step is taken at levels higher than that of the logistician and concerns the determination of which military objectives are to be accomplished. This decision is often qualitative and involves matters of national importance that are decided through political processes and at high levels in the Department of Defense. The second step involves consideration of alternative methods of accomplishing the stated objectives. This step, in turn, has two phases. The first involves the evaluation of alternate systems for accomplishing the objective. This decision will also be made at fairly high levels, although the logistics implications of choosing among various alternatives must be considered, as has previously been noted. The second phase, which directly concerns the ILS logistician, involves the determination of how the various elements of ILS should be used in combination to support the weapon system which has been decided upon. It is at this point that the logistician must undertake an economic analysis, valuing the ILS resources which each alternative method requires.

The logistician may find the use of a model helpful in making his analysis.[14] A model is basically a method for studying relationships which exist among variables abstracted from the total environ-

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[14]Paul H. Rigby, Conceptual Foundations of Business Research (New York: John Wiley and Sons, Inc., 1965), pp. 109-127 contains a very comprehensive discussion of model-building that is of general application.

ment. These can range from a simple word description to a complex mathematical formulation. Appropriateness of a model depends upon the variables selected and the soundness of the theory upon which it is constructed. Its value lies in how well it is able to predict outcomes, so that the consequences of any particular choice can be adequately estimated. The main point here is that the logistician generally will need some type of framework within which he can manipulate the abstracted variables, contributing to the total cost of the alternatives which he is evaluating.

The final step in an economic analysis involves making a decision based on one or more criteria selected for choosing among alternatives. In the private sector, the criterion is often stated to be profit maximization. As has been previously noted, maximization of "military worth" is a more difficult problem. To the ILS logistician, however, the problem which presents itself is ultimately one of combining inputs so as to permit attainment of the desired level of availability at lowest resource cost. In many cases there will be subproblems such as non-availability of particular resources, lack of a clearly defined organizational structure, or failure of the accounting system to generate useable cost data. In such situations the logistician may be unable to optimize his position, and can only try to achieve an input combination that is more efficient than any other feasible combination presently possible.

Isoquants and the production function in ILS. -- Microeconomics frequently makes use of indifference curve analysis in demonstrating geometrically the determination of efficient use of resources. Strictly speaking, an indifference curve is a locus of points on a graph which denotes combinations of any two different items selected in such a fashion that the potential consumer of the items is indifferent as to which combination he receives. All points on the described curve provide him with the same degree of satisfaction. The indifference curve graph thus has a quantity variable on both axes. The shape or slope of an indifference curve can be considered as indicating the marginal rate of substitution that exists between two items, A and B.

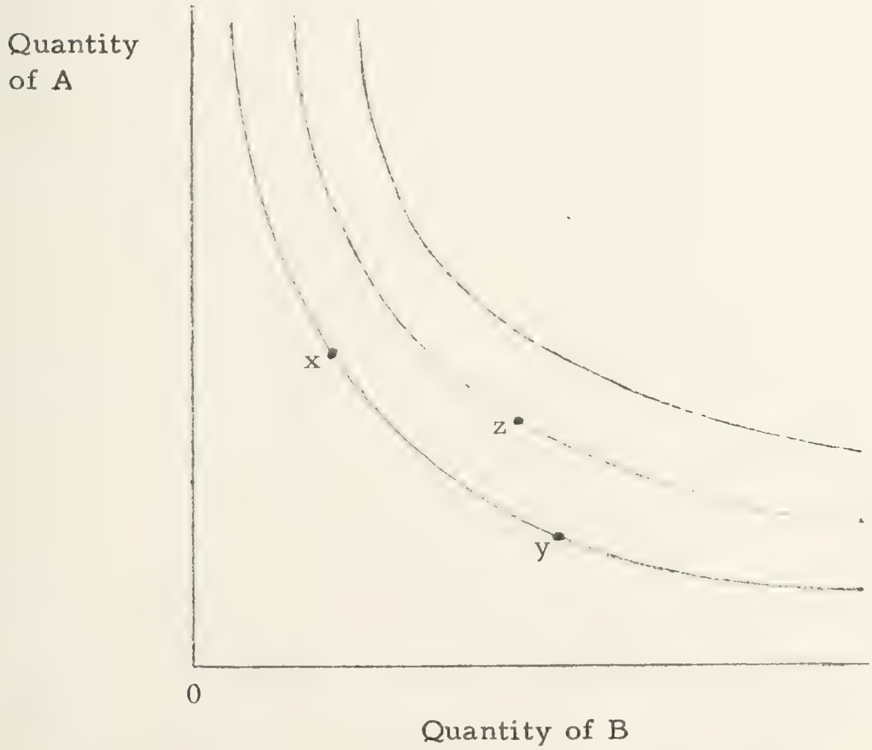

Fig. III-1 -- Illustration of a partial family of indifference curves.

The curve is convex to the origin because as more and more units of A are given up the remaining units become increasingly more valuable to the consumer and require more units of B in substitution. There exists an infinitely large number or family of such curves since an infinite number of combinations are theoretically possible and an indifference curve passes through each point describing a combination. Figure III-1 depicts three members of such a family of curves. In Figure III-1, x and y are equivalent combinations of A and B, while combination z, lying on a higher indifference curve, is preferred to either x or y. An economic problem is said to exist when (1) only a subset of all the possible combinations is available, and (2) at least one of the unavailable combinations is preferred to any of the available combinations. The consumer is best off when he selects that available combination of A and B which lies on the highest indifference curve.

The general principles of indifference curve analysis can be carried over into the study of production or output. Output capable of being produced is a function of the inputs used. In economic theory, this relationship between inputs and output is known as a production function. It can be stated as $Q = f(x_1, x_2, \cdots, x_n)$ where Q is the output and there are n possible inputs. The production function is valid over a particular period of time, and depends upon the current state of technology. The notion of a production function implies the

solution of a prior problem of technological efficiency. That is, given the state of technological knowledge, the production function indicates the maximum output available from any given combination of inputs. Thus the production function itself assumes that the problem of technical efficiency has already been solved. The economist's -- or logistician's problem is to make choices which result in economic efficiency.

In this section, a static analysis with respect to changes in technology will be carried out so that input-output relationships existing at one point in time may be more clearly brought into focus. It is recognized that this procedure limits the analysis to some extent since changing technology is a factor the logistician does have to deal with. It is here, however, assumed that the output being sought by the logistician is some given level of weapon system availability or reliability and that he varies the input mix so as to attain the output at lowest possible cost given conditions then existing. All other factors are assumed to be held constant (ceterus paribus).

Consider now the general static case of obtaining a given output (level of weapon system availability) by varying the quantities of logistics inputs. The ILS logistician has, supposedly, ten elements which he can vary in reaching the output level. In order to keep the example two-dimensional for the present, however, assume that only two variable inputs are to be used. The productive output that obtains

from the use of these inputs can be indicated by curves which look like indifference curves. The curve which connects the various combinations of inputs which yield a fixed level of output is called an isoquant or isoproduct curve.[15] The production function in this case can be represented by a family of these isoquants. Quantities of output are the same at all points on an isoquant; i.e., output is a constant. Figure III-2 shows one typical isoquant. Movement up this isoquant (i.e., to the northwest) would mean that increasingly larger sized increments of A must be applied in production to compensate for given decrements of B in order to keep the level of output fixed. And as more and more units of A are used, it becomes increasingly more difficult, in the sense of the required increase of A, to maintain the level of output by giving up units of input B. This is an economic relationship similar to that of diminishing returns.

As with indifference curves, an infinite family of isoquants is required, theoretically, to describe the production function fully. Slopes of these isoquants depend on the technical substitutability of the inputs and are equal to the negative of the ratio of the marginal product of the inputs. The curve in Figure III-2 is convex, indicating

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[15]Isoquants are not true indifference curves. Watson, however, in Price Theory and Its Uses, p. 169 notes that they are sometimes called "production indifference curves." The indifference curve maps a preference relationship whereas the isoquant deals with a relationship involving technical substitutability.

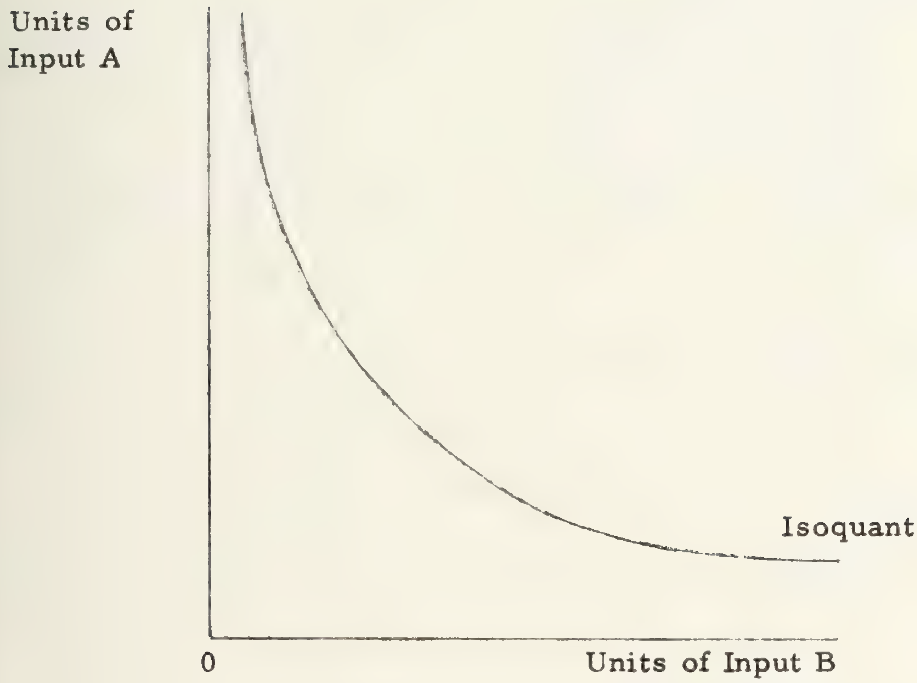

Fig. III-2 -- Illustration of the production function.

less than perfect substitutability. Further, at no point, can two isoquants in the same family intersect, since this would imply that a higher level of output could be attained by reducing the amount of one of the input quantities without increasing the other.

The problem which faces the ILS logistician in the context of this theoretical presentation is to determine that combination of inputs which is economically efficient in achieving a desired output (level of weapon system availability). Economic efficiency -- as opposed to technical efficiency -- requires a choice in the face of meaningful

constraints, in this case a budget limitation. At any one point in time the logistician is limited not only by the combinations that can actually be used due to the current state of technology, but also by the availability of financial resources allocated to his particular task. In order then to decide which of the technically efficient points is optimal, costs must also be brought into consideration. Each input has an opportunity cost, or price, which will influence the extent of its use in the face of the budget constraint.

Figure III-3 illustrates an example of this budgetary constraint. Limiting positions can be established on each of the two axes determined by the cost of each input and the available budget. A line can then be drawn between the respective limiting positions, such a line

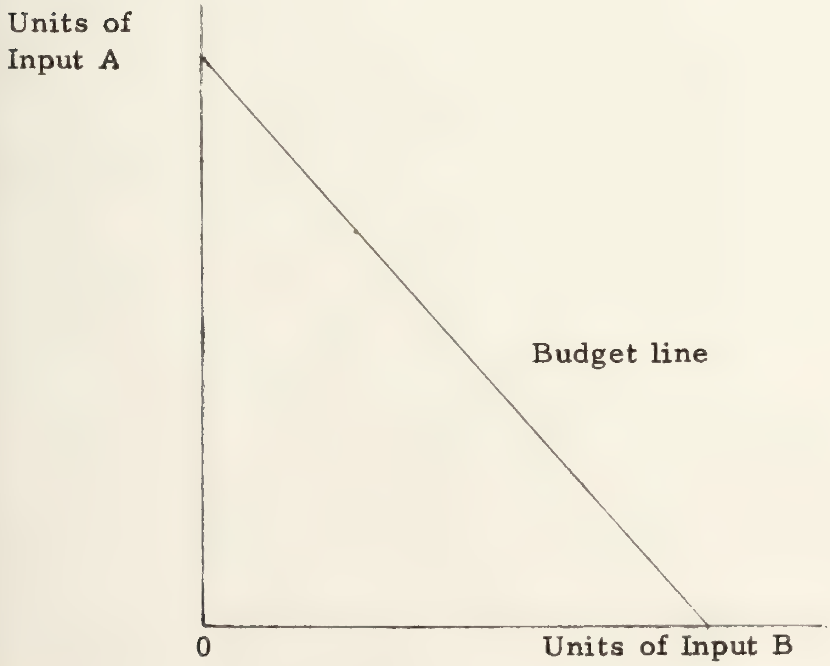

Fig. III-3 -- Illustration of a budget line.

being called the budget line, or exchange curve. The slope of this line or curve is determined by the ratio of the marginal costs of the two inputs. The budget line can also be thought of as an isocost curve. In Figure III-3, this curve is shown as a straight line, indicating a condition of constant unit cost of the inputs. Other isocost lines may, of course, be drawn closer to the origin, representing combinations which would result in expenditure of less than the full budget allocation.

Suppose now that the ILS logistician has to consider the use of only two of the elements previously defined as comprising the Integrated Logistic Support System. These elements have a stated cost per unit, and the logistician faces a budget constraint. Assume that the two ILS elements are (1) sets of spares and repair parts (Supply Support), and (2) sets of support and test equipment. The object, as previously developed, is to combine these inputs in an optimal fashion. The productive output attainable from these valuable inputs is measured in this case in terms of inherent availability of the weapon system -- availability being defined as previously indicated in Chapter II, i. e.,

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} .$$

To support some given level of availability, say 95 percent, these two inputs can be employed in various combinations and are

therefore to some extent technical substitutes. Figure III-4 shows a hypothetical locus of points representing discrete combinations of the two inputs which it has been estimated would provide a desired 95 percent level of availability. This figure indicates that as more spares and repair parts are provided the system probably can be more easily maintained although this increase will be subject to diminishing returns.

If the points shown in Figure III-4 are now connected, an isoquant would result such that every point on the curve would represent an input combination capable of yielding 95 percent availability. Similarly, a family of isoquants based on engineering estimates could be constructed for other levels of availability as indicated in Figure III-5.

Each point on any one curve represents as technically efficient a combination of the two inputs as any other on the same curve. A move can be made to a higher level of availability only by trading off between the two inputs in such a manner that total output is increased. The problem in proceeding to successively higher isoquants arises, of course, from the fact that there is an opportunity cost involved in procurement of the inputs, and funds are limited to the Acquisition Manager for logistic support purposes. The logistician must therefore bring cost of the inputs into his calculations. Assume now that the logistician has a given budget and that a 95 percent availability

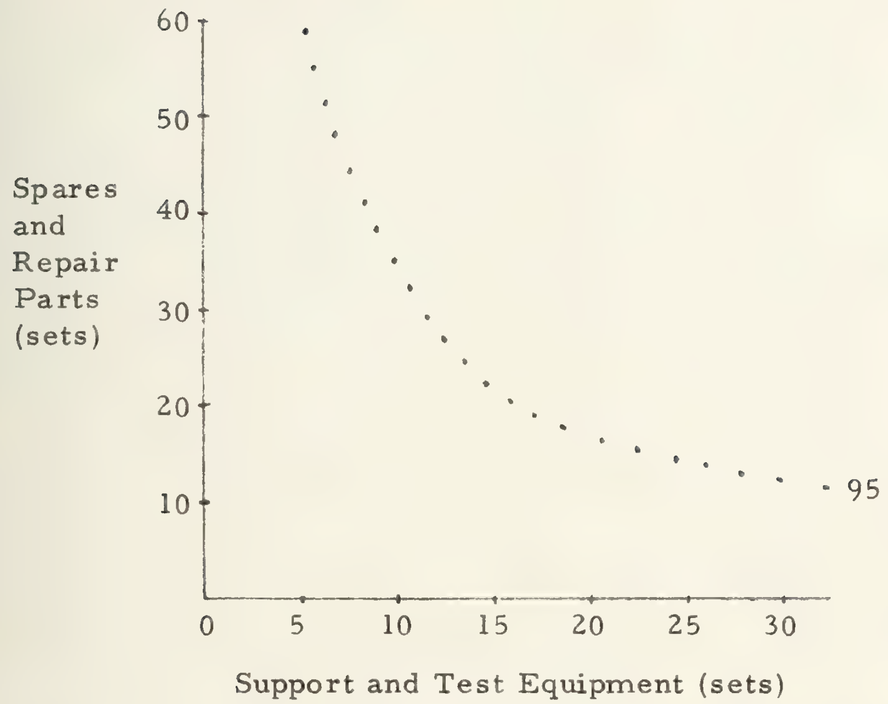

Fig. III-4 -- Illustration of 95 percent availability combinations.

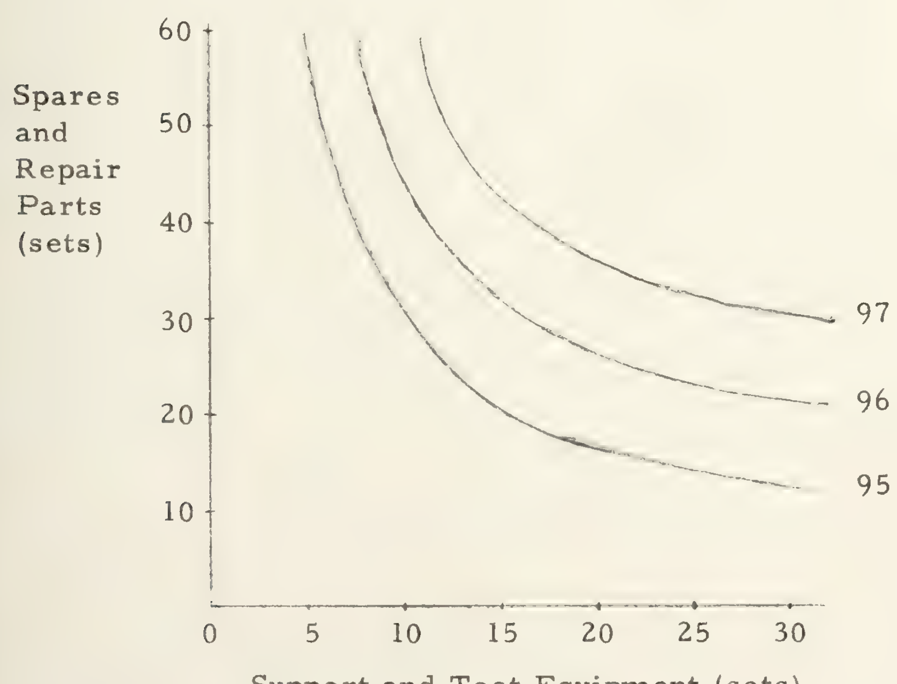

Fig. III-5 -- Illustration of a family of availability isoquants.

objective has been assigned as the minimum objective for logistics support. If the entire budget were to be spent on spares and repair part sets, a certain number of these sets could be obtained. Likewise, the logistics budget could also theoretically be spent entirely on sets of support and test equipment. Calculations under each of these two assumptions will provide the limiting positions on the two axes.

Assume now for sake of simplicity that one set of support and test equipment can be procured at the same cost as two sets of spares and repair parts and that both items are obtained under conditions of constant unit cost. A straight isocost line can be drawn between the respective maximum points on the axes. In theoretical economics, the optimum position that would now be possible to be reached is that point where the line representing the available budget is just tangent to the highest availability isoquant. In general, we may say that tangency of isoquants and isocost lines indicates minimum cost positions. However, in the situation that has been described above, the goal is attainment of 95 percent availability with the minimum expenditure of logistics funds. In this case, the optimum position is the lowest budget line which is just tangent to the 95 percent availability curve. This position is indicated by the point E in Figure III-6. [16]

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[16]It is, of course, possible that the budget constraint and the availability criterion are inconsistent; i.e., that the budget line representing the maximum expenditure allocated to the task in question lies

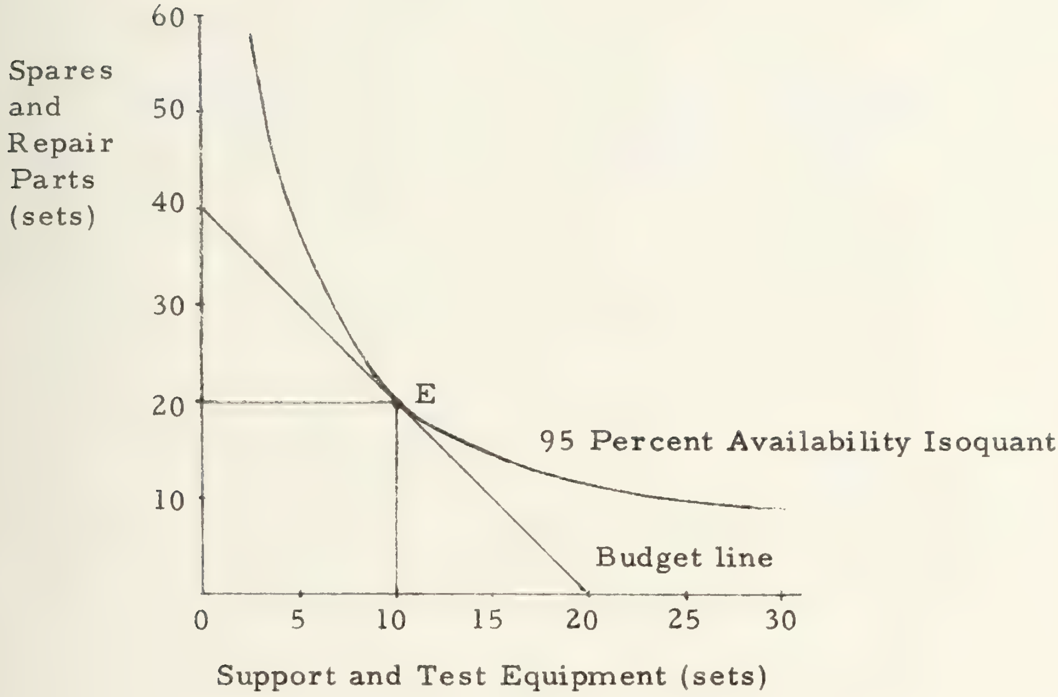

Fig. III-6 -- Illustration of an optimum position.

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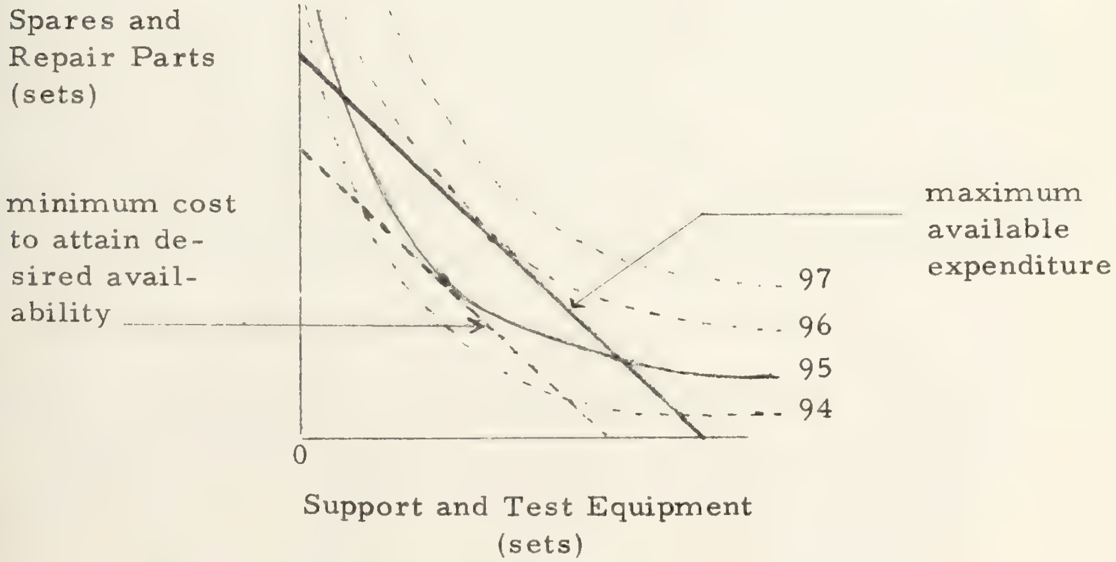
everywhere below the 95 percent availability isoquant. In Figure III-6 we assume this is not the case. A more complete graph might show:



The indicated optimum position would thus involve the procurement of twenty sets of spares and repair parts and ten sets of support and test equipment. Calculation of the figures required in order to make such a determination will undoubtedly not be easy. Yet if the logistician goes through these steps, he will be able to obtain most of the data he needs and at the very least he may thereby be saved from making gross errors.

It should be mentioned at this point that it is possible in the situation being discussed to attempt to either (1) maximize availability ($\geq \overline{A}$) subject to some fixed budget B, or (2) minimize B ($\leq \overline{B}$) subject to $A = \overline{A}$. Figure III-6 illustrates the latter type of optimization. Here there would be only one isoquant but many possible budget lines to the left of the maximum line to consider. Figure III-7, shown below, illustrates the former situation where the optimum position is considered to be tangency of the maximum budget line with the highest availability curve. In this case there are many isoquants to consider, but only one budget line.

Elements of maximization. -- The principles involved in the preceding theoretical example of two valuable inputs can be further extended to apply to a problem such as use of the ten potential ILS inputs. This can be done, as Hitch and McKean point out, by simply dropping the requirement for proof through the method of plane

geometry.[17] Proceeding to this more complex situation then, assume once again a constant unit cost for any input, designated by c_i.[18] Also assume that it is desired to maximize logistic support contribution to weapon system availability, A, through an optimum combination of ILS inputs, subject to the constraint of a given budget, B. Let $x_1, x_2, \cdots, x_{10}$ represent the ten variable ILS inputs. The object then is to maximize the value of the function $A(x_1, x_2, \cdots, x_{10})$ subject to the budget constraint, B. As before, only feasible combinations should be considered. The budgetary constraint will preclude some combinations as will present non-availability of some inputs. In addition, some combinations, although feasible in financial terms, may not be practically possible.[19]

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[17]Hitch and McKean, The Economics of Defense in the Nuclear Age, p. 117.

[18]For a general discussion of the cases of constant and increasing average unit costs, see ibid., pp. 367-369. Development of these cases involves determination of the marginal cost of inputs. A maximum position is found to be reached when the marginal product of each input just equals its marginal cost. For many problems involving military logistics support of sophisticated weapon systems, however, constant unit cost of the logistic inputs is a valid assumption since these items are purchased by lot, or are frequently available at some constant unit cost in inventory.

[19]Ibid., pp. 385-387 considers programming techniques whereby manpower as well as budget constraints are present. By use of the general technique described infra, however, combinations can simply be eliminated if they involve the use of any inputs not available.

In addition to calculus, by assuming both A and B to be linear, the problem can be handled by linear programming as well using solution techniques such as the simplex method.[20] Linearity is often a reasonable assumption, particularly in the specific area under consideration, and it greatly simplifies the mathematics involved. In such a situation, the logistician may readily make use of the technique. Even if A and B are not precisely linear, the use of linear programming is likely to achieve results of at least a fairly close approximation.

Often, however, in an ILS problem it may be that the variable inputs to be manipulated are relatively few in number and discrete, with the budget standing as the only constraint.[21] In such a case the logistician might follow a procedure which essentially involves consideration of relative marginal products of the inputs. The marginal product of any input, x_i, may be identified as the contribution which one extra unit of x_i makes to A. Measured in small enough units,

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[20]It is not the purpose of this study to review the methods of linear or other types of mathematical programming. However, for a good discussion of application of the simplex method in management type problems, see Harold Bierman, Charles J. Bonini, and Warren H. Hausman, Quantitative Analysis for Business Decisions (3rd ed.; Homewood, Ill.: Richard D. Irwin, Inc., 1969), pp. 256-296.

[21]Of interest in this regard is the discussion of mathematical determination of maximum and minimum in the discrete case contained in Ragnar Frisch, Maxima and Minima: Theory and Economic Applications (Chicago: Rand McNally & Company, 1966), pp. 8-14.

this marginal product is equal to the partial derivative of A with respect to x_i. We would normally expect this marginal product to be positive, e.g., the procurement of one more set of spare parts would probably contribute in some positive manner to an increase in the value of A.

Now the budget, B, imposes an input limitation on the logistician which can be indicated by the inequality

$$B - \sum_{i=1}^{n} c_i x_i \geq 0$$

where x_i is any input and c_i is its cost.

Having established the basic inequality, a search can then be made of feasible combinations which would both satisfy the inequality and result in minimum acceptable availability. One particular combination can then be found to be the maximizing solution through systematic comparisons with other possible combinations. The point here is not to advocate one specific procedure that will be always applicable and useful. Rather it is to indicate that it may often be possible for the ILS logistician to make use of rather simple tools which can improve his ability to make an efficient economic choice in many trade-off situations. One writer notes in this regard that: "...there is a very real need for the logistics planner to have a rapid, automated proce-

dure to handle the volumes of logistics predictions, trade-offs, and analyses with the required accuracy."[22]

Applications

The Collins Radio Company produces certain electronic equipment and parts which are used in aircraft production by the military and also by NASA in the space program. Many of these items are designed to perform somewhat similar functions in various uses. Higher reliability levels are deemed more essential in some applications, however, and the parts for these uses are therefore more costly. Reliability Level 1 shown in Table III-2 was designed for equipment which uses standard military parts and standard production processes and controls. Level 2 indicates equipment designed for use in the new F-111 aircraft. Level 3 parts were designed for use in the Gemini space program and level 4 in Apollo. In each case, a production quantity of 800 units was assumed in estimating costs. As previously described, MTBF stands for the reliability concept mean-time-between failure expressed in hours.

Assume hypothetically now that a logistician has a need to evaluate the procurement of sets of weapon system spare parts of the type indicated in Table III-2 as well as sets of test equipment. These

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[22]Moore, An Integrated Approach to Logistic Analysis, p. 10.

TABLE III-2

COST FACTORS VERSUS RELIABILITY LEVELS
(Reliability Expressed in Terms of MTBF Hours)

	Reliability Levels			
Cost Factors	1	2	3	4
Parts Improvement				$ 1,250
Piece Parts Cost	$1,300	$1,700	$2,500	4,000
Fabricated Parts Cost	600	600	750	900
Labor and Overhead	1,350	1,350	1,600	2,200
Prime Mfg. Cost	3,250	3,650	4,850	8,350
Special Charges	350	500	650	850
Total Mfg. Cost	3,600	4,150	5,500	9,200
G & A and Profit	800	910	1,200	2,000
Selling Price	$4,400	$5,060	$6,700	$11,200
MTBF	150	240	560	1,200

Source: Collins Radio Company, Life Cycle Costing (Cedar Rapids, Iowa: Collins Radio Company, 1966), p. 3-2.

are the only inputs of concern at present. Assume also that Collins Radio Company is the only possible producer of the spare parts. The logistician thus has four spare part options to consider in combination with the other inputs for trade-off purposes. He should observe, of course, that increases in the selling price of 15, 55 and 250 percent are associated with MTBF improvements by factors of 60, 370 and 800 percent respectively. It is also implicit that the logistician will insure that contractor charges to overhead are contractually proper so as not to bias the final decision.

Assume next that the logistician determines he can procure as many sets of test equipment as may be needed that will meet requirements at the constant price of $5,000 per set. The logistician's concern would now be with the levels of availability and reliability required by the equipment design.[23] Assume engineering estimates indicate 500 MTBF hours to be the minimum acceptable level for reliability in this use and the highest possible level of availability is desired, but <u>at least</u> 95 percent. The logistician will then decide on the spare parts with a reliability level of 560 MTBF hours and costing a constant $6,700 per set. If the logistician has a maximum budget of $5.5 million which he can allocate between the two material items, he will want to purchase that quantity of sets of spares and test equipment which will result in the highest level of system availability (at least 95 percent) possible from his constrained budget. The first step would be for the logistician to have isoquants calculated by design engineers for 95 percent and higher levels of availability. As before, the slopes of the isoquants are given from the marginal rate of technical substitution of the inputs at the indicated point. If we let the level of avail-

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[23] Recall that inherent availability is defined as being composed of reliability measured in MTBF, and maintainability, measured in MTTR. In Table III-2, the levels shown for MTBF assume that nothing can be done to increase these figures by working with elements of maintainability.

ability be called A, spare parts x_1, and test equipment x_2, then we have a problem of attempting to maximize $A(x_1, x_2, \cdots, x_n)$ where all variables other than x_1 and x_2 are being held constant. We then have $dA = A_1 dx_1 + A_2 dx_2 = 0$, from which we calculate $\frac{dx_1}{dx_2} = -\frac{A_2}{A_1}$, the slope of the isoquant where x_1 is measured on the y axis and x_2 is measured on the x axis.[24]

To make such calculations, the design engineer would require estimates which indicated the rate at which sets of spare parts could be substituted for sets of test equipment. Assume that such data are obtained and isoquants plotted as indicated in Figure III-7. The logistician can now construct his budget line. Since the budget is \$5.5 million, a maximum of 1100 sets of test equipment at \$5,000 per set or 820 sets of spare parts at \$6,700 per set can be obtained. Under the given conditions of constant unit cost, a straight budget line is drawn and tangency with the highest isoquant looked for. This will indicate the highest level of availability possible within the \$5.5 million budget constraint. The final calculation with tangency at point E, as indicated in Figure III-7, is for 597 sets of spare parts and 300 sets of test

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[24]Here A_1 is the partial derivative of A with respect to x_1. It thus represents the marginal product to A of an additional small unit of x_1. Similarly, A_2 is the partial derivative of A with respect to x_2.

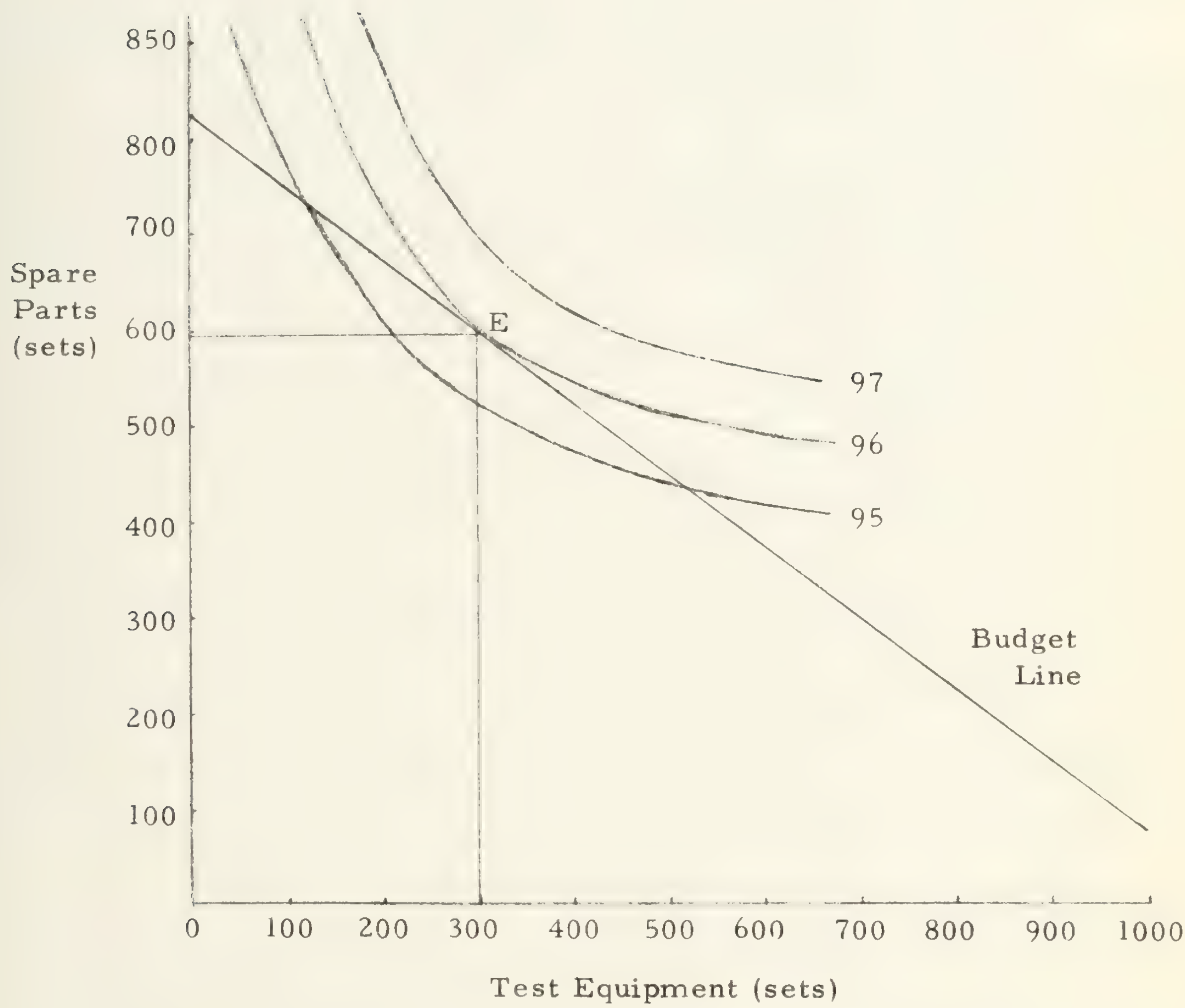

Fig. III-7 -- Calculation of purchase quantity of two ILS inputs.

equipment, reaching 96 percent availability.[25]

In any calculation such as that above, certainly the technical competence of each bidder and the prospect of his being able to

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[25]See the Appendix to Hitch and McKean, The Economics of Defense in the Nuclear Age for discussion of a method for handling a problem involving multiple inputs.

achieve predicted levels of availability and MTBF must be given careful consideration by the logistician. As a part of this kind of evaluation the potential supplier's quality control program should be closely studied. This should help to preclude "buying in" by questionable contractors. It should also help stress the point that logistics support problems must be considered early in the system design stage. It has often been the case in the past, for instance, that an over-investment in spare parts came to be considered necessary because support considerations weren't adequately taken into account in the basic equipment's initial design.[26] An example of such a situation can be seen in the case of the airborne digital computer of the fire control system of the F-106 aircraft. This system was initially designed in 1956. A few years ago, the system began requiring increasingly large amounts of logistic support resources. A subsequent redesign of the system resulted in estimated annual savings of some 200,000 maintenance man-hours valued at more than $3.5 million.[27]

Evaluation of potential contractor performance. -- Another advantage of the use of economic trade-off studies in ILS is that weapons system contractors will come to realize that even though the

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[26] Worden, "Integrated Logistics Support," p. 21.

[27] Morris, keynote address presented at the Electronic Industries Symposium, March 7, 1968.

system might actually have little or no competition from direct substitutes, general competition for the logistician's limited budget resources must impose restraints on behavior. The Department of Defense does not at present obtain as much data as are necessary in some cases to make trade-off analyses in the most effective manner. This is a separate problem and beyond the scope of this paper. Here it can only be assumed that information for trade-off analyses is available. Scherer, however, having studied such information as has in the past been obtained, makes the point that it should be possible to award a large number of weapon system and equipment contracts on the basis of after-the-fact evaluation of prior contractor performance and that this procedure would be much preferable to any system involving an extension of government controls.[28]

In any case, it should be possible for the logistician to obtain, in many instances, enough information to make at least preliminary trade-off analyses through a search of past contractor performance records and other available procurement data and through requests for supporting trade-off studies from potential contractors.

A problem related to the above involves the point that much available subjective information is not being used in any systematic

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[28] Scherer, The Weapons Acquisition Process: Economic Incentives, p. 362.

manner despite the fact that "...it is clear that both objective and subjective considerations must be carefully weighed if sound program decisions are to be made."[29] It is to this problem which we now turn in Chapter IV.

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[29]Peck and Scherer: The Weapons Acquisition Process: An Economic Analysis, p. 249.

IV

BAYESIAN STATISTICAL DECISION THEORY APPLIED TO ILS

> ... The time would seem to be at hand when we should think about Bayesian priors and the applications of statistical decision theory to defense planning.... [1]

Relevant Aspects of Statistical Decision Theory

In the discussion thus far we have largely neglected the influence of uncertainty on the decision-making process. Because the course of events cannot definitely be known in advance, uncertainty cannot be avoided and decisions must be made based on predictions of the future. Statistical decision theory provides a means for rationalizing the decision-making process under conditions of uncertainty by placing probabilities on the likelihood of certain events occurring in the future. Decision theory or inductive statistics has been described as: "... the development of methods which will enable the analyst to calculate and subsequently minimize the gamble which automatically is assumed in every problem of estimation or predic-

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[1] John R. Meyer, "Comments on Institutional Structures and Defense Spending," in Issues in Defense Economics, ed. by McKean, p. 263.

tion."[2] Inductive statistics and decision theory thus permit the practitioner to proceed more intelligently by allowing for the determination and assumption of "calculated risk."

General statistical decision theory, regardless of the specific decision-making approach to be followed can be considered to be essentially composed of the following major elements:

1. The set of all available (alternative) actions.
2. The set of all unknown "states of nature," or occurrences which might take place and against which the possible alternative actions are planned.
3. A listing of the consequences which will result from taking a particular action when any state of nature results.
4. The data.
5. A collection of all possible strategies, or mapping of actions to be taken depending on results which come from combining the data together with the consequences indicated above across the states of nature.
6. Criteria for deciding on an optimal strategy to attain the desired objective.

Following an approach which makes use of these elements the

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[2] Dick A. Leabo, Basic Statistics (3rd ed.; Homewood, Ill.: Richard D. Irwin, Inc., 1968), p. 110.

decision-maker would be in a position to evaluate the consequences of taking any particular action when any state of nature subsequently occurs. In a military situation, however, this may be very difficult primarily because of the problem involved in valuing consequences in a quantitative sense. Since this problem does exist, it is, therefore, essential for the military decision-maker to have clearly established at the outset the objective which is to be obtained, such as the achievement of a particular level of system availability for the least expenditure of funds, or, alternately, the achievement of the highest possible level of availability within a given budget constraint. He can then proceed to use all available evidence in an attempt to attain the objective in as efficient a manner as possible following as closely as possible the above general procedure.

Statistical inference makes strong use of the mathematical concept of probability. Although a rigorous development of the theory of probability is beyond the scope of this study, it would be appropriate to discuss how we shall interpret the meaning of the term.

Classical versus the subjectivist approach. -- In classical

theory, the term probability is used to mean relative frequency of occurrence in the long run. Thus if one were to roll a fair die a large number of times, he could expect that any one of the sides would appear about one-sixth of the time, reflecting some intrinsic, uncontrollable variability of results. This approach to probability is particularly important in scientific uses where it is possible to obtain a data base from observations of repeated trials performed under identical conditions. Decision-making under such conditions is secondary to the process of conducting the experiments and obtaining results. If it is known ahead of time, as in the die experiment, that a certain number of equally likely outcomes are possible, then probabilities can be assigned prior to conducting the experiment.

Relative frequency can thus be conceived of as some underlying number, or kind of long-run stability which idealizes reality. In the classical theory relating to equally likely outcomes, the probability of an event A occurring, designated P(A), is thus defined as the number of equally likely outcomes favorable to A divided by the total number of equally likely possible outcomes.

Reference has been made above to the idea of random variation of results. The notion of a random variable is used to mean any rule which assigns a real number to each possible outcome of an experiment. If X, then, is a random variable with possible values

$x_1, x_2, \cdots, x_n$ having related probabilities $p(x_1), p(x_2), \cdots, p(x_n)$, then this latter collection of numbers can be called the probability distribution of the random variable X. Now the sum of the products of each x_i times its related probability is called the "expected value" of X, or E(X). The expected value of a random variable is interpreted in terms of long-run, average expectation. This notion of expected value can be of particular importance in the case of those systems and support element acquisitions which involve substantial research and development effort.

It should also be noted at this point that regardless of how probabilities are assigned to individual events, they must satisfy three basic postulates of finite probability theory:[3]

1. Any probability P(A) is a non-negative number: $P(A) \geq 0$.
2. The probability of a certain event is equal to unity.
3. If the events A and B are mutually exclusive, we have the additive rule: $P(A + B) = P(A) + P(B)$.

The classical notion of probability has its widest application, as stated above, in repetitive experiments under controlled conditions.

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[3]Harald Cramér, The Elements of Probability and Some of Its Applications (New York: John Wiley & Sons, 1955), p. 33.

The strict classicist would not want to estimate the probability of occurrence of an event such as life on Mars -- life is either there or it isn't and once the answer is obtained the experiment would not need to be repeated. (In fact, it could not be repeated.) The classical approach can, however, easily be visualized as applying to a situation where the problem is to estimate the probability of picking a "good" item from a continuous production run where it is possible to relate the long-run relative frequency of the number of good items to total production. In this instance, no judgments based on any subjective feeling or "intuition" of the item selector as to the likelihood of obtaining a good item are formed prior to selection.

In addition to this type of situation, however, there exists a class of non-programmed, business type decisions in which it would appear necessary, or at least advisable, to investigate how management or other expert opinion feels about the probability that certain occurrences will (or will not) take place. Probability in this context can be thought of as a series of weights or degrees-of-belief attached to possible outcomes. Personal or subjective judgments are systematically combined with sample data in arriving at "updated" probabilities and ultimately a decision. In considering a problem such as that of life on Mars, the subjectivist approach would hold that different degrees-of-belief are possible for different per-

sons, even when all have examined the same basic evidence.

This subjective approach will hereafter be referred to as "Bayesian" since it makes use of Bayes' theorem in the decision process.[4] Bayes' theorem is a consequence of the statistical definition of conditional probability and can be stated as

$$P(A_i/H) = \frac{P(A_i)P(H/A_i)}{\sum_{i=1}^{n} P(A_i)\ P(H/A_i)}$$

where there are n distinct events A_1, A_2, $\cdots$, A_n comprising the set and H is another event contained in the set.[5] The use of this theorem in the ILS setting is discussed below.

The advantage of the general Bayesian approach for purposes of this study is that it allows for the development and use of a subjec-

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[4]In 1763, an essay by the late Rev. Thomas Bayes appeared in <u>Philosophical Transactions of the Royal Society</u>. It was entitled "An Essay toward Solving a Problem in the Doctrine of Chances." The proposition which he stated and proved therein has since been further developed and is today known as Bayes' theorem.

[5]See Hymans, <u>Probability Theory</u>, pp. 262-263 for a derivation of Bayes' theorem from the definition of conditional probability. Two events, A_1 and A_2, are considered statistically independent if and only if the probability of simultaneous occurrence of these two events is equal to the product of their individual probabilities. This means that the fact that A_1 has happened (or not) gives no clue as to the probability of A_2 happening (or not). If, however, A_1 does influence or have something to do with the probability of occurrence of A_2, then it can be said that A_2 is "conditional" on A_1. We can thus speak of the probability of A_2 given A_1, or A_2/A_1.

tive prior probability distribution for an unknown parameter. This distribution can, of course, be constructed through use of the techniques of economic analysis discussed in Chapter III, or by any other method which suits the preference of the decision-maker. The process of Bayesian analysis actually begins, however, only after the prior probability distribution has been developed.

Two views of probability have thus been discussed -- one, the notion of long-run relative frequency and the other, the idea of weights, or degrees-of-belief which can be updated by considering new evidence. Before demonstrating how Bayesian analysis can be used to update degrees-of-belief, however, let us first demonstrate the use of Bayes' theorem considering for the moment only certain sample evidence. Assume that 100 identical items were tested at the plants of three contractor-bidders with the following results:

TABLE IV-1

RESULTS OF TESTS IN THREE CONTRACTOR PLANTS

Contractor	Items Passed	Items Failed	Total
A	97	3	100
B	96	4	100
C	92	8	100
Totals	285	15	300

Assume further that the logistician is interested in ascertaining the probability that a particular random failure occurred in the plant of Contractor C. To put this information in the notation used above for Bayes' theorem, let A_1 = Contractor A, A_2 Contractor B, A_3 Contractor C and H the condition fail. From the information presented and the definition of probability, the following calculations can be made:

$$P(A_1) = \frac{100}{300} = .33^+$$

$$P(A_2) = \frac{100}{300} = .33^+$$

$$P(A_3) = \frac{100}{300} = \underline{.33^+}$$

$$1.00$$

$$P(H) = \frac{15}{300} = .05$$

$$P(H/A_1) = \frac{3}{100} = .03$$

$$P(H/A_2) = \frac{4}{100} = .04$$

$$P(H/A_3) = \frac{8}{100} = .08$$

$$P(A_1/H) = \frac{3}{15} = .20$$

$$P(A_2/H) = \frac{4}{15} = .27$$

$$P(A_3/H) = \frac{8}{15} = .53$$

Thus the probability of the random failure having occurred in the plant of Contractor C is seen to be .53. Suppose, however, that only incomplete data had been available and, specifically, none of the final three probabilities conditional on H were directly known. The logistician, must then calculate the conditional probability $P(A_3/H)$ from Bayes' theorem. From our previous definition of this theorem we have

$$P(A_3/H) = \frac{P(A_3)\ P(H/A_3)}{\sum_{i=1}^{3} P(A_i)P(H/A_i)} \quad .$$

To obtain the denominator, we can calculate

$$P(A_1)P(H/A_1) = (.33)(.03) \cong .0099$$

$$P(A_2)P(H/A_2) = (.33)(.04) \cong .0132$$

$$P(A_3)P(H/A_3) = (.33)(.08) \cong .0264$$

From the definition of conditional probability we then have

$$\sum_{i=1}^{3} P(A_i)P(H/A_i) = P(H) \cong .0099 + .0132 + .0264 = .0495 .$$

Substituting into the equation gives

$$P(A_3/H) = \frac{(.33)(.08)}{.0495} = \frac{.0264}{.0495} = .53 .$$

Thus once again the probability of the failure having occurred in the plant of Contractor C is calculated to be .53 or a 53 percent chance.

<u>Strategy selection and use.</u> -- Perhaps one of the most important distinctions between the classical and subjective approaches to probability is apparent in the method of selection of strategies and the procedure which is then followed. For example, a decision-maker might assume a situation in which he is facing a rational opponent and that both sides have full and complete information. As a second possible alternative, he might assume that he is facing unknown "nature" with incomplete information. Game theory, particularly that of the two-person, zero-sum type, would fall into the first type of situation. The second type of situation, however, visualizes the decision-maker as (1) not having complete knowledge and (2) facing an opponent who he cannot assume will behave in a rational manner. Hence in this case definite statements about long-run relative frequency cannot be made in advance. In such instance the decision-maker must then decide whether or not he wishes to make prior judgments. For one reason or another, judgments might not be made. Any particular outcome could then be initially assumed as being equally likely and sample or test data relied on entirely.[6] In this case, the classical decision theory procedure would be followed, including calculation of optimum sample sizes and collection of data, and decision processes

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[6] In Bayesian terminology, this is known as a non-informative prior.

such as Minimax followed.[7]

It may be, however, that management does have subjective judgments which it wishes to make use of together with sample or test data in arriving at a decision. Bayesian analysis provides a vehicle for doing this. This analytical tool permits the combining of sample evidence with the prior probability distribution to calculate a new, revised distribution based on both of these factors. This new distribution is known as a posterior probability distribution. Through the use of this analysis, evaluation is permitted such that the larger the sample size, i.e., the richer the objective evidence, the more the weight placed on it as opposed to the prior subjective judgment. Calculation of revised probabilities should appeal to the ILS logistician since it would enable him to put to use that which he has learned "from experience."[8] The logistician can employ his own internal techniques to establish a prior probability distribution.[9] Modifications

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[7]See Hitch and McKean, The Economics of Defense in the Nuclear Age, pp. 195-197, 201-202 for a general discussion of use of Minimax and game theory in a military setting.

[8]Robert C. Shook and Harold Joseph Highland, Probability Models with Business Applications, ed. by Ester H. Highland (Homewood, Ill.: Richard D. Irwin, Inc., 1969), p. 80.

[9]It should be stated at this point that it is still an open question as to how this can best be done. By their very nature prior probabilities must be viewed as "personalistic" and hence might vary from individual to individual. Bruce W. Morgan points out in his An Introduction to Bayesian Statistical Processes (Englewood Cliffs, N.J.:

can then be made as further evidence is obtained across the early stages of a system's life cycle. Such an approach would enable

1. ILS personnel to be early contributors to the initial decision-making process, and active participants throughout the subsequent review process.
2. All available evidence, including expert subjective opinion to be brought to bear in helping to estimate the crucial parameter(s).
3. A better final choice to be made through the merging of subjective and objective evidence, or at the very least to provide a basis for inquiry as to the differences which might exist between government and contractor estimates.

In addition, the logistician in some cases may face a situation in which the number of potential contractors are few and/or the number of items to be tested or samples that can be taken limited. Bayesian analysis can be a useful procedure in such cases as well.

The binomial distribution. -- In many random experiments, the observer is confronted with an either-or outcome. A looked for

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Prentice-Hall, Inc., 1968), p. 24 that "One main distinguishing feature of the Bayesian approach, then, lies in its willingness to make direct use of these personal, or subjective, probabilities. . . ." Bayesian statistics thus can be looked on as a procedure for making use of personal judgments, indicating that relevant experience is important. The subjective information is thus to be considered intrinsically as valuable as the sample information.

occurrence either takes place or it doesn't. Occurrences on one trial also may have no influence on the outcome of another trial. For example, consider the random selection of an electron tube for a performance test. The tube will either meet specifications or it will not. These tubes do not "wear out" in the same sense as do certain mechanical devices. Rather they fail in a random manner and the fact that a tube may be operating at t hours tells us nothing about what to expect from this same tube at t+1 hours. A probabilistic statement could be made, however, about the life expectancy of this general type of tube.

Performance of an experiment of this type is often referred to as a Bernoulli trial. When an experiment consists of determining the total number of successes out of n independent Bernoulli trials with the success probability remaining constant at p for every trial, the experiment is called a binomial experiment and the parameters of its probability distribution are n and p. Tables have been constructed which show the results of "expanding the binomial" and specify the probability that a failure will occur exactly r times in n trials.[10] These tables are, however, somewhat

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[10]The notation used in the case of Bernoulli trials is $b(r;n,p)$, which refers to the probability of achieving exactly r successes in n trials in which the probability of success on each trial remains constant at p, and the probability of failure is $q=1-p$. The resultant binomial probability density function is then derived from

lengthy.[11] Other distributions are thus sometimes used because they are easier to manipulate mathematically and provide reasonably close results. The binomial distribution has been singled out here for discussion, however, because many of the tests in which the logistician will be involved have outcomes which fall in this pattern and hence because of the use made of it in the examples which follow.

Bayesian Analysis in the ILS Environment

Let us now consider the hypothetical development and use of the prior and revised (posterior) distributions in an ILS context. Suppose that an ILS logistician is confronted with a decision situation. He has been asked whether the contractor-submitted support plan of a newly proposed weapon system appears feasible. Two alternative actions are available:

1. Action a_1 -- advise that the support plan is feasible.
2. Action a_2 -- advise that the support plan is not feasible.

The unknown states of nature in this case may be considered to be the levels of availability which the support plan can actually provide. The

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$\binom{n}{r}p^r q^{n-r}$, $0 \leq r \leq n$. Also, $\sum_{r=o}^{n} \binom{n}{r}p^r q^{n-r} = 1$, indicating that the sum of the probabilities obtained adds to one in all cases.

[11]For example, see Frederick Mosteller, Robert E. K. Rourke, and George B. Thomas, Jr., Probability With Statistical Applications (Reading, Mass.: Addison-Wesley Publishing Company, Inc., 1961), pp. 433-452.

logistician and his staff do not at this point take actual samples such as items from the production runs of potential suppliers of support equipment. Neither is any other type of test of material conducted. Such things, however, as prior performance of the support plan contractor in meeting commitments, the recent record of logistic support of similar or related systems, and probable availability of support personnel of the kind needed are considered. As a result of a subjective evaluation of this and any other pertinent information available, the staff develops the following probability distribution.[12]

Decimal Statement of Levels of System Availability (p)	Probability That the Support Plan Can Maintain no Higher Than This $p(P_{(p)})$
.80	.20
.90	.25
.95	.50
.99	.05
	1.00

By this procedure, then, an assignment of probabilities has been made to the "likely" values of the unknown p as the result of exercise of expert subjective judgment by the logistician and his staff.

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[12]Results obtained through use of Bayesian analysis, as developed infra, can depend importantly on the values determined for the prior probability distribution. While the logistician thus will attempt to arrive initially at the best possible prior distribution he may well wish in the final decision to subject the results to a sensitivity analysis based on using slightly different values to see how the decision is changed as changes are made in the priors.

The distribution, whose probabilities sum to one, may be called the "prior distribution of p."

Suppose now that a 95 percent availability level has been established by design engineers as the minimum that should be insured. The logistician then draws up the following decision rules:

1. Action a_1 if $E(p) \geq .95$.
2. Action a_2 if $E(p) < .95$.

Now it is possible that the logistician might make his decision simply on the basis of the subjective prior probability distribution which he and his staff have just developed. If he were to do so in this case, he would calculate $E(p) = .910$ and hence would take action a_2, advising that the contractor's logistics support plan did not appear feasible.[13]

Probably, however, he would not be satisfied with this. The system hardware procurement may involve millions of dollars, and the logistic support elements at least that much. Moreover, the system might be considered to have a unique value for national defense

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[13] The calculation of the E(p) is as follows:

p	P(p)	p· P(p)
.80	.20	.160
.90	.25	.225
.95	.50	.475
.99	.05	.050
		.910 = E(p)

whose worth could be very great, but difficult to calculate in precise monetary terms. The subjective prior probability distribution and its expected value could be considered by the logistician as a sort of benchmark, but he might well want to obtain additional, current data, based on sample evaluation.

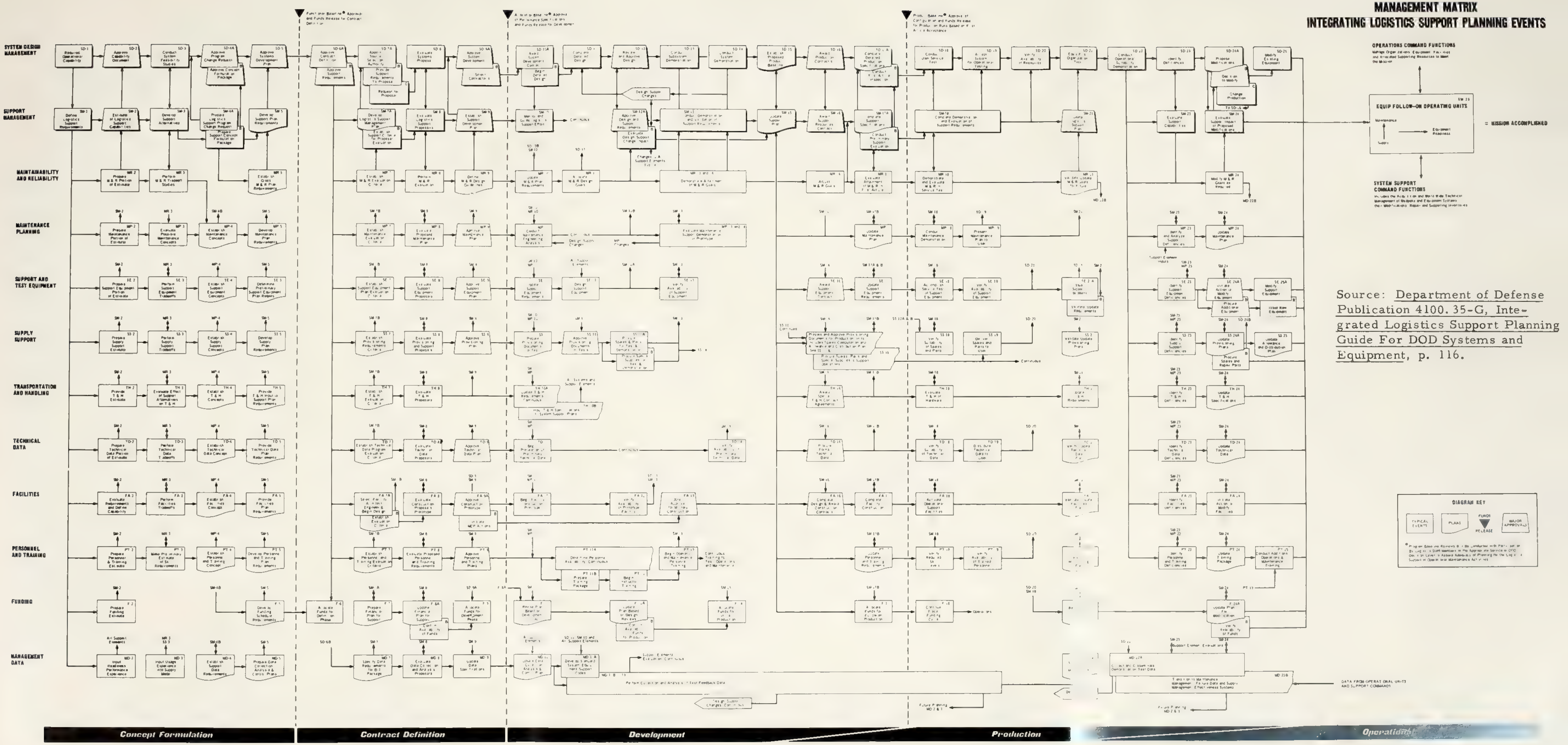
In fact, it can be noted that under the ILS implementing directives numerous opportunities present themselves for obtaining and making use of additional information. Exhibit IV-1 portrays a management matrix which integrates the elements of logistics support planning with system design management across the system's life cycle. Referring to Exhibit IV-1, for example, consider the sequence of events shown opposite the ILS element Support Management. In particular, note the following steps which indicate the ability to update information:

1. SM-8. The contractor's logistic support proposal is evaluated concurrently with his system proposal. This is considered in subsequent establishment of a support development plan.
2. SM-13. Demonstrations and validation of support requirements are carried out leading to updating of the support plan.
3. SM-17A and SM-18. Validation continues following first article and service tests.

These steps are but examples. The significant fact is that as the basic system hardware undergoes periodic testing, so does the logistics

EXHIBIT IV-1

MANAGEMENT MATRIX
INTEGRATING LOGISTICS SUPPORT PLANNING EVENTS



Source: Department of Defense Publication 4100.35-G, Integrated Logistics Support Planning Guide For DOD Systems and Equipment, p. 116.

support plan. It should be noted here that it is possible to perform tests using models and mock-ups quite early in the system life cycle and substantially before it is possible to make actual operational tests. The support plan, therefore, can be updated at these early stages with a relatively small expenditure of resources.[14]

A situation can thus be seen to exist in which it is possible to pool previous information and subjective judgment with sample evidence and test information to permit the calculation of an updated or revised probability distribution which is referred to as the posterior probability distribution, or, in the context of the hypothetical example being discussed, the posterior distribution of the unknown p, in view of which decisions can be made or revised. It should be noted that values can be continually updated simply by using a posterior distribution as the prior distribution in the next round of data collection and

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[14]For a more detailed discussion of the steps in development of the logistics support plan during which opportunities exist for updating, see Holsclaw and Carlson, "Integrated Logistic Support: The Life-Cycle Task of Support Management," especially pp. 3-7. Of significance also is the following statement contained in DOD directive 4100.35: "Each system or equipment project shall include a plan for functional and environmental tests or analyses to assess periodically whether the logistic support planned will maintain the system or equipment effectively and efficiently. These tests shall be combined to the maximum extent practicable with reliability, maintainability, performance, and complete system tests. When the need is justified, separate logistic support tests or analyses also shall be scheduled."

evaluation. Decisions previously made can be reversed, at a saving of resources, if subsequent information shows a disparity between the subjective evaluation and test results. At the very least, grounds for further tests and improvements are established.

In the hypothetical case under discussion, assume that, on the basis of recent performance, the logistician is confident of all logistics elements except for certain critical spare parts, and the overall system availability can therefore be equated to the reliability of the spares. According to the system design these spares are to be supplied out of present Navy inventory, and are located in various stock points throughout the United States. The logistician then learns from the Supply Support element manager that twenty-five of these spare parts are available at a nearby location. Assume now that the engineers can devise an appropriate non-destructive test.[15] The twenty-five items are then tested and only one fails to pass. This now provides the logistician with two pieces of information which he wishes to combine.

Assume that a random failure pattern for the item in question has been established so that use of the binomial distribution is appropriate. Remember that he will take action a_1 if

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[15]Should a non-destructive test prove impossible to devise then, of course, test samples would have to be much smaller.

Posterior E(p) $\geqq$ .95.

Now let us proceed to indicate how Bayes' theorem and the binomial distribution can be used to develop the revised or posterior distribution once the prior has been developed. Recall that the subjectively estimated attainable availability level expressed as a proportion p is considered as a random variable with the prior probability distribution P(p) as follows:

p	P(p)	p· P(p)	
.80	.20	.160	
.90	.25	.225	
.95	.50	.475	
.99	.05	.050	
	1.00	.910	= Prior E(p)

The binomial distribution and Bayes' theorem can now provide the means for combining this subjective prior probability distribution with the sample evidence. Our sample was of twenty-five items, of which twenty-four passed. Denoting the number which passed by T, we have T = 24 or T/n = 24/25 = .96 as the proportion passing. Recalling that a priori considerations had admitted four possible values of the actual system availability, p, we can calculate the probability of observing that T = 24, or T/n = .96 for each of these values of p.[16] Assuming

[16]It is important to note that T/n, the proportion passing, is itself a statistically unbiased and consistent estimator of p. In addition, this estimator becomes more efficient as n increases. Our

use of the binomial distributed $b(r;n, p)$ or $b(24;25, p)$, a series of "Test P" values can be calculated such that this "Test P" is actually the conditional probability $P(T=24/p)$ for each value of p. Thus for the prior p value of .80 we calculate:

$$P(T=24/p=.80) = \binom{25}{24} (.80)^{24}(.20)^{1} \cong .024$$

Likewise for the other values of p:[17]

$$P(T=24/p=.90) = \binom{25}{24} (.90)^{24}(.10)^{1} \cong .199$$

$$P(T=24/p=.95) = \binom{25}{24} (.95)^{24}(.05)^{1} \cong .365$$

$$P(T=24/p=.99) = \binom{25}{24} (.99)^{24}(.01)^{1} \cong .196$$

The use of Bayes' theorem is now important in proceeding to develop the updated or posterior distribution and posterior $E(p)$. From the theorem we have, for the first value of p:

$$P(p=.80/T=24) = \frac{P(p=.80)P(T=24/p=.80)}{\{P(p=.80)P(T=24/p=.80)+P(p=.90)P(T=24/p=.90) + P(p=.95)P(T=24/p=.95)+P(p=.99)P(T=24/p=.99)\}}$$

$$= \frac{(.20)(.024)}{(.20)(.024)+(.24)(.199)+(.50)(.365)+(.05)(.196)} = \frac{.0048}{.0048+.0498+.1825+.009}$$

---

problem here is that for n equal to only twenty-five, we wish to use more than just sample evidence. See Hymans, Probability Theory, p. 267.

[17] As previously mentioned, these values can be obtained from binomial distribution tables. For example, see Mosteller, Rourke and Thomas, Probability With Statistical Applications, p. 443, using n=25, x=24, and p=.80, .90, .95 and .99 to obtain these calculated values.

Thus we have $P(p=.80/T=24) = \frac{.0048}{.2469} \doteq .019.$[18] In similar fashion, values can be calculated for the other levels of p and listed for convenience in the following format:

p	P(p)	Test P	P(p)x Test P	P(p) x Test P / P(T=24)
.80	.20	.024	.0048	.019
.90	.25	.199	.0498	.202
.95	.50	.365	.1825	.739
.99	.05	.196	.0098	.040
			.2469	1.000
			=P(T=24)	=P(p/T=24)

With these results and the prior E(p) previously developed, the logistician is now in position to calculate the posterior E(p):

p	P(p)	p· P(p)	P(p/T=24)	p· P(p/T=24)
.80	.20	.160	.019	.015
.90	.25	.225	.202	.182
.95	.50	.475	.739	.702
.99	.05	.050	.040	.040
	1.00	.910	1.000	.939
		=Prior E(p)		=Posterior E(p)

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[18]This is directly comparable to the prior value P(p=.80)=.20. Initial, subjective, research had arrived at a 20 percent chance of 80 percent availability. The test results, which indicated T/n=.96 (96 percent availability) serve to reduce the likelihood of only 80 percent availability so that we now have: Probability of 80 percent system availability given a particular test result of 96 percent availability =P(p=.80/T=24)=.019 < .20.

Thus we have a situation where the prior $E(p) = .91$, the sample test $= 24/25 = .96$ and the posterior $E(p) = .939$. The two pieces of evidence have been weighted and combined. Since the posterior $E(p) < .95$, the logistician recommends course of action a_2. Had the posterior $E(p)$ been such that a favorable decision to proceed resulted, the posterior distribution could then be maintained and used as a prior distribution for some subsequent test. This is important because in the ILS procedure, several tests are provided for prior to actual hardware procurement. A planned procurement could thus be terminated, if necessary, at any of several research and development test points prior to letting of the actual fabrication contract.

In the above example the subjective judgment of the logistician and his staff in effect outweighs favorable test results. Perhaps the subjective judgment was based on an experience involving support of a similar system, in which unfavorable results occurred. In any event, under Bayesian procedure, as the sample size increases the relative weight given to sample evidence increases. Therefore, if he desired to be even more positive, the logistician might take steps to test identical items located at another location and so increase the sample size. Such tests of reliability could also be carried out by contractors under government supervision as part of the prime contract, or as a special test and evaluation sub-contract. Certainly it

would seem that industry in any case would need to make stringent tests in its own self-interest, and the results could then be made available to the logistician under appropriate contractual arrangements. Moore notes in this regard that: "Reliability is a characteristic that a product has put into it by the factory. And in order to find out if its products are reliable, the factory must test its output."[19] It should also be emphasized that the type of analysis discussed above could conceivably be carried out with any of the ILS elements. If carried out separately, it would be possible to determine which, if any, of the elements fell short and hence would require upgrading prior to use.

The role of subjective judgment. -- But why, one might ask, *should* we allow subjective judgment to influence the final decision. The logistician is a professional in management of the military business function and as such is in a unique position to add to the decision process in a positive manner. Classical techniques of statistical decision theory make no provision for this. Judgment based on past experience can be a very important asset. One writer, in fact, has stated that it is "perhaps *the* significant ingredient in most interesting

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[19] Franklin G. Moore, *Manufacturing Management* (5th ed.; Homewood, Ill.: Richard D. Irwin, Inc., 1969), p. 328.

management decisions."[20] It is this type of decision which permits non-quantitative factors to be taken into consideration. Such decisions can, as we have already noted, be very important in defense applications. What is being discussed here, of course, has nothing to do with snap judgment or judgment based on limited prior experience. Rather it is sound judgment based on long experience exercised by intelligent, highly competent logistics managers. This chapter deals then with how this valuable judgment may be effectively combined with quantitative, objective evidence in a systematic manner to provide the basis for sound decision-making at the logistician's level.

In the hypothetical example developed above, the logistician would have chosen action a_1 had he limited himself entirely to sample evidence. Using the Bayesian approach, however, he chose instead action a_2. Writing about situations of this type, a proponent of Bayesian analysis states: "The Bayes-type approach is superior to an approach which limits itself to frequentist-objectivist (classical) considerations except in situations where it may be taken for granted that the two approaches lead to results which, for the purpose at hand,

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[20] William T. Morris, Management Science, A Bayesian Introduction (Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1968), p. 21.

are not worth distinguishing."[21] Provision for subjectivity is also important in that it allows choices to be slanted in accordance with the responsible decision-maker's preference as to various consequences and his judgment concerning the role of uncertainties involved. Thus internal consistency is introduced into the decision-making process regardless of how much subjectivity enters into construction of the prior probability distribution. Should seniors in the chain of command not approve of a particular decision-maker's subjective preference scale, appropriate changes can be made to introduce new preferences.

Applicability of Bayesian Analysis in ILS

We have seen that the necessity for qualitative judgments at high government levels does to some degree limit the usefulness of pure quantitative techniques in solving defense problems. Thus military planners have in the past often made decisions based almost entirely on past experience. With the coming of systems analysis to the DOD, however, such judgments came to be looked on as being of very little value. Systems analysis groups, however, perhaps pushed too far in attempting to quantify all factors involved in a problem. As one observer has noted, the primary result of this was "the mislabeling

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[21] William Fellner, Probability and Profit (Homewood, Ill.: Richard D. Irwin, Inc., 1965), p. 59.

by the civilians of their own intuitions and judgments as 'analysis'."[22]

Judgment, of course, should be combined with objective evidence. It is obvious in this regard that the present procedure for obtaining sufficient empirical data from contractors needs strengthening, so that the logistician's decision-making process can be improved. Of perhaps equal importance, however, is the necessity for the establishment within the Department of Defense, readily accessible to the logistician, of a group capable of evaluating the more technical information obtained from test samples and historical information and also capable of rendering other technical assistance. Indicating that such a need exists, one researcher has observed, for example, that "In all but three of the twelve programs covered by our case studies, there existed within the buying agency no group with the technical competence needed for a thorough independent analysis of contractor estimates."[23] This is a key point. Assuming evaluations are provided by such a group (or other means), then Bayesian analysis can fill a definite need of the logistician. It will enable him, independently, to review and, in effect, to adjust contractor estimates to a

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[22]James R. Schlesinger, "Organizational Structures and Planning," in Issues in Defense Economics, ed. by McKean, p. 206.

[23]Scherer, The Weapons Acquisition Process: Economic Incentives, p. 65.

more realistic level. The approach recommended for the cases which follow assumes this service is available.

<u>Uncertainty in the military setting</u>. -- How one might ask, is it possible to deal with uncertainty? One obvious way utilized in the past has been simply to ignore any factors not lending themselves to ready quantification. The attractiveness of this approach comes from the fact that the weapons system acquisition process is characterized by a set of uncertainties different from those found in normal business activity and particularly difficult to quantify. The main deficiency, of course, is that potentially critical factors may be purposely left unevaluated in any manner. At the other extreme is the belief that all factors are quantifiable if only the problem can be studied long and hard enough. This is also an unrealistic alternative and one which can result in deceptively clear conclusions. It is, for example, virtually impossible to estimate in precise terms the loss that would occur should a system not maintain 95 percent availability due to failure of some support element to perform as expected. What is left, then, is a middle ground, wherein all factors possible are reduced to quantifiable terms and subjective judgment is then intermixed.

We have been discussing decision-making primarily during the early stages of a system's life cycle. It is during this period that uncertainties are much greater than at some later period in the system

life cycle. It would be advantageous if mathematical models developed to deal with these uncertainties could initially be kept as simple and flexible as possible. More specific and detailed calculations can then be made later as the weight of empirical evidence begins to supplant subjective judgment. Then, too, it may turn out that because of uncertainties, ILS resources could conceivably be combined in more than one way to achieve a desired output. In such a situation, as Hitch and McKean point out: "The simultaneous development of two or more of the possible choices is frequently preferable to developing only one -- no matter how superior it appears to the experts."[24] If more than one combination is feasible, then, the logistician may well want to retain the capability to use each until uncertainties are lessened through subsequent tests and evaluation. Statistical quality control tests (referred to in Chapter III) in contractor plants can, of course, provide important objective information which may contribute to a reduction of this uncertainty.[25]

ILS Case Examples

A number of procurements have recently been carried out

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[24] Hitch and McKean, The Economics of Defense in the Nuclear Age, p. 265.

[25] For additional information dealing with S. Q. C. procedures, see Moore, Manufacturing Management, pp. 681-707.

under a Department of Defense Test Program to assess the practicality of the concept of life cycle costing. Two of these cases are detailed below together with an indication of how a Bayesian approach might have been used by a logistician to provide clearer direction. These examples involve relatively small procurements, dollar-wise, and cover only a few of the possible ILS elements, but nevertheless do demonstrate through the use of actual procurement data the potential for a subjective Bayesian approach.[26] Before proceeding, it should be noted that the items tested in these cases are assumed to fail due to random acts of nature rather than because of "wearing out." In fact, it has been authoritatively stated, referring to the demand rates which often follow such failures, that ". . . the demand rates for many spare parts are virtually independent of part age, at least for the typical, rapidly-obsolescing weapon systems."[27] The binomial probability distribution has therefore been considered appropriate in the Bayesian development which follows.

Example one -- 600 horsepower non-magnetic diesel engines

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[26] These examples are developed from ILS data presented in Logistics Management Institute, Life Cycle Costing in Equipment Procurement: Supplemental Report (Washington, D. C. : Logistics Management Institute, February, 1967), pp. 89-92.

[27] W. H. McGlothlin and Eloise E. Bean, Application of the Bayes Technique to Spare Parts Demand Prediction (Santa Monica, Calif. : The RAND Corporation, January, 1961), p. 5.

for mine warship ships. -- This case concerns a multi-year procurement contract let under the procedures of formal advertising. Criteria for award was established as the lowest cost combination of initial unit purchase price and cost of repair parts for a ten-year period. A fuel consumption penalty was devised for the sample tests.

Decision procedure for selection of a contractor was as follows: Each company competing for the award submitted repair parts schedules and a fixed price option for repair parts in their bids. The Invitation for Bids and the subsequent contract detailed specific fuel consumption tests which were to be performed on 5 percent of the engines delivered. A contractor was permitted to exceed his bid average specific fuel consumption (ASFC) by 0.010 pounds per brake horsepower per hour without a price penalty. A penalty was to be required for fuel consumption which exceeded bid ASFC by a larger amount. This penalty took the form of adding on to the total bid price a relative-inefficiency evaluation calculated as: (Test ASFC - Bid ASFC - 0.010) x $100,000 x Number of Engines Delivered.

Based on this formula, the contract was to be awarded to the bidder whose total price was lowest. Bids were subsequently received on this basis from four companies, tests conducted and these results obtained:

Company	Purchase Price	Ten Year Repair Parts	Fuel Consumption Penalty	Total
W	$19,614	$ 6,132.87	$ 0	$25,746.87
X	27,200	Not Stated	3,334.67	?
Y	31,900	3,694.77	0	35,594.77
Z	63,374	18,318.41	2,633.33	84,325.74

Because data pertaining to the ten year cost of repair parts was not submitted, Company X's bid was considered non-responsive. The contract award was made to Company W on the basis of the data presented.

This procurement was significant from the ILS standpoint in that it was one of the first in which logistics considerations actually were made part of the award criteria. Let us assume, then, that in this case the assigned ILS logistician has been presented with these data by the design engineer and the procurement agency and has been asked to comment on the ten-year repair parts estimate prior to award of the contract. The question thus is how might a Bayesian approach have been used to sharpen the decision-making process in the interest of helping to insure the most efficient allocation of resources. In the first place, it should be noted that there is no evidence the ten year repair parts cost figures represent discounted values, based on years in which actual expenditures must be made. This should be accomplished in the manner described in Chapter III, using for the present

the discount rate recommended by the Department of Defense. In the analysis which follows, it will be assumed this has been done, resulting in the following:[28]

Company	Discounted Ten Year Repair Part Cost Estimate
W	$ 5,700
Y	3,500
Z	14,500

Since the contract provides for a fixed price option on the repair parts, this is also expected cost of the parts.

The logistician and his staff now review the contractors' past records for delivery of reliable equipment and submission of realistic repair parts schedules; data concerning any similar contractor equipment currently in operation; and other available pertinent procurement data and expert opinion. Based on evaluation of these data, prior probability distributions relating to the repair parts schedules are developed for each of the three actively competing contractors. In the tables below, p in each case stands for the unknown maximum percent level of engine availability capable of being reached; P(p) stands for the prior probability that the contractor's repair parts schedule

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[28]The use of a more appropriate discount rate is discussed at some length in Chapter V, infra.

can maintain the given level of availability; and p· P(p) gives the prior probability distribution, its total representing the expected value in the prior distribution of p.

Company W			Company Y			Company Z		
p	P(p)	p· P(p)	p	P(p)	p· P(p)	p	P(p)	p· P(p)
.80	.20	.16	.80	.10	.08	.80	0	0
.90	.25	.23	.90	.20	.18	.90	.15	.14
.95	.50	.48	.95	.65	.62	.95	.75	.71
.99	.05	.05	.99	.05	.05	.99	.10	.10
	1.00	.92		1.00	.93		1.00	.95

Now assume that the proposed contract states that the engine should achieve a minimum of 93 percent availability and the logistician sets as his objective the attainment of this minimum at the lowest possible cost. Company W's bid now begins to look less favorable, since award should be to the bidder whose bid is the most advantageous, price and other factors considered (see Chapter II). By saving $10,000 in the award, it is possible that design availability may not be met at all, or only after subsequent costly modifications. Some mine warfare ships might even be placed out of service. At least there would seem to be a basis here for concern. There is no evidence, however, that such considerations actually entered into this contract award.

Let us continue to assume that the award has not yet been made. The logistician and design engineer confer and determine that there are six especially critical parts common to all three of the contractor's

repair parts schedules. Two of these are in sufficient stock in the Navy Supply System. The other four parts are produced in the contractors' plants, by means of normal production run process. At this point, then, it is extremely important that there be available an appropriate group within the Department of Defense which the logistician can turn to for assistance:

1. To review and evaluate general quality control procedures in the contractors' plants.
2. To devise and conduct appropriate sample tests for the four critical repair parts to be fabricated in these plants. If the tests must, of necessity, be destructive, then the government would have to be prepared to negotiate suitable reimbursement. Should a contractor have devised tests which are judged to be suitable, then the results could simply be verified.
3. To devise and conduct sample tests for the two critical repair parts in Navy inventory, for this particular application.

Indeed the establishment and staffing of such a group with highly capable personnel is a major recommendation of this study. A reputable commercial testing agency could possibly be placed under DOD contract to perform the actual evaluations. I shall hereafter in this study refer to this recommended organization as the Design

Evaluation Group. Such an organization could have great potential value in helping to direct scarce defense resources efficiently.

Assume now that samples are selected and tested at the three contractors' plants and from Navy inventory. The two items in Navy inventory experienced no failures. Results from the three contractors' plants were:

	Contractor W	Contractor Y	Contractor Z
Items tested	20	20	20
Items passed	18	19	20
Percent pass	90	95	100

The Design Evaluation Group also notes as a general observation that Contractor Z's quality control procedures seem to be more stringent than Y's, and Y's better than W's. With this information and his prior probability distributions, the logistician now proceeds to develop the necessary posterior distributions using a binomial distribution table to obtain Test P figures. (See footnote 17 above.)

Company W

p	P(p)	Prior E(p)	Test P	P(p)· Test P	P(p/T=18)	Posterior E(p)
.80	.20	.16	.137	.0274	.141	.113
.90	.25	.23	.285	.0713	.368	.331
.95	.50	.48	.189	.0945	.487	.463
.99	.05	.05	.016	.0008	.004	.004
	1.00	.92		.1940 = P(T=18)	1.000	.911

Company Y

p	P(p)	Prior E(p)	Test P	P(p)· Test P	P(p/T=19)	Posterior E(p)
.80	.10	.08	.058	.0058	.019	.015
.90	.20	.18	.270	.0540	.172	.155
.95	.65	.62	.377	.2451	.783	.744
.99	.05	.05	.165	.0082	.026	.026
	1.00	.93		.3131	1.000	.940
				= P(T=19)		

Company Z

p	P(p)	Prior E(p)	Test P	P(p)· Test P	P(p/T=20)	Posterior E(p)
.80	0	0	.012	0	0	0
.90	.15	.14	.122	.0183	.050	.045
.95	.75	.71	.358	.2685	.728	.692
.99	.10	.10	.818	.0818	.222	.220
	1.00	.95		.3686	1.000	.957
				= P(T=20)		

The logistician then summarizes these results.

Company	Total Bid Price	Expected Level of Availability
W	$25,314	91.1
Y	35,400	94
Z	87,874	95.7

On the basis of this analysis, the logistician notifies the procurement agency that Company W does not appear to be capable of providing the minimum level of availability specified by the contract and that Company Y appears to be low bidder "price and other factors considered." Thus the use of Bayesian analysis in this example could have resulted

in more efficient allocation of resources in the long run, given the assumptions made. The question might well be asked at this point what the logistician would have done if Company Z's bid price were only slightly greater than that of Company Y, say \$37,874 instead of \$87,874. Such a situation points up clearly why it was emphasized at the beginning of this chapter that the logistician must have identified his exact objective in each case. In this case his general objective was to provide for a minimum of 93 percent availability at the lowest possible cost recognizing that higher levels of availability would be preferable if no budget constraint existed. With this decision criterion, his choice would still be Company Y.

<u>Example two -- tunable master oscillator klystron for the Hawk missile system.</u> -- This case involved a competitive negotiation, with the authority to negotiate granted on the basis of Armed Services Procurement Regulation 3-210.2(xiii), which permits negotiation "when it is impossible to draft...adequate specifications or any other adequately detailed description of the required supplies or services." The Request for Proposal stated that award would be made to the company with the lowest cost proposal, based on the following formula:

$$\frac{P+S}{L} - T - N_{am} - N_{fm} - F_{se} - F_s$$

where: P = unit purchase price

S = one tube's share of the cost of special tooling

L = average hours of tube life

T = temperature coefficient

N_{am} = AM noise

N_{fm} = FM noise

F_{se} = spurious emission amplitude

F_s = frequency stability input voltage

Performance levels were specified for the values T, N_{am}, N_{fm}, F_{se}, and F_s. Two potential suppliers returned quotes on this basis. The government then purchased eighteen tubes from each of these companies for test purposes. Upon completion of tests, the following data were listed:

Company	P	S	L	T	N_{am}	N_{fm}	F_{se}	F_s
X	$1,230	$19	546	0	-.19	-.03	0	.475
Y	1,239	0	973	0	-.19	.01	0	.469

Applying these data to the referenced formula resulted in the determination of the following "Evaluation Results" for the two companies:

Company	Evaluation Result
X	2.0325
Y	0.9844

Award was made to Company Y on this basis, even though its purchase price, considered alone, was higher.

This case is particularly important for ILS because in it a test was devised and used for the logistic component under proposed procurement such that performance as well as price was to be considered in the award. It would be interesting therefore to ascertain if a Bayesian approach might have been possible. Assume that the logistician once again has access to the Design Evaluation Group, and he asks (1) what would be the probable highest formula value that could be interpreted as a favorable result, and (2) what are the probabilities associated with various proportions (p) of tubes which would achieve this favorable result?

The Design Evaluation Group then conducts a review of the proposed action, including appropriate discussions with design engineers and the procurement agency. Estimating the likely range of the various formula component values based on previous test results as well as subjective considerations, this Group determines that values of 1.5 or less achieved through use of the formula could generally be considered as "favorable." Using this criterion the following prior probability distribution for the characteristic p is developed by the Design Evaluation Group where p represents the proportion of tubes which would yield a formula value ≤ 1.5:

p	P(p)	Prior E(p)
.70	.40	.280
.80	.25	.200
.90	.20	.180
.95	.10	.095
.99	.05	.050
		.805

Since this distribution covers all tubes produced by all potential bidders, however, the logistician, based on past records and experience, develops separate subjective prior probability distributions for each of the bidders as follows:

Company X			Company Y		
p	P(p)	Prior E(p)	p	P(p)	Prior E(p)
.70	.30	.210	.70	.45	.315
.80	.25	.200	.80	.30	.240
.90	.20	.180	.90	.15	.135
.95	.15	.143	.95	.10	.095
.99	.10	.099	.99	0	0
	1.00	.832			.785

We may interpret these results as meaning that of all klystrons that could be submitted for test on this bid, the Design Evaluation Group feels that about 80.5 percent could be expected to achieve a formula reading on test of about 1.5 or less. From this universe, then, the logistician subsequently subjectively estimates that the items from Company X would have an expected value of about 83.2 percent of reaching this result, and Company Y 78.5 percent. This, of course,

places a premium on the logistician having ready access to past procurement and reliability data and also on his training and competence to make such evaluations. (It will be a recommendation of this study that these conditions be met.)

It has been stated that eighteen tubes from each company were purchased and tested. Assume that formula results <u>for each test</u> were obtained, with the following results ($x \leq 1.5$ being considered "favorable"):

Company	Tests Conducted (n)	Favorable Test Results (T)	Percent Favorable (T/n x 100)
X	18	14	77.8
Y	18	16	88.9

With this objective data, the logistician now completes his calculations to determine the posterior E(p) for each company.

Company X

p	P(p)	Prior E(p)	Test P	P(p)· Test P	P(p/T=14)	Posterior E(p)
.70	.30	.210	.168	.0504	.421	.295
.80	.25	.200	.215	.0538	.450	.360
.90	.20	.180	.070	.0140	.117	.105
.95	.15	.143	.009	.0014	.012	.011
.99	.10	.099	0+	0+	0+	0+
	1.00	.832		.1196 = P(T=14)	1.000	.771

Company Y

p	P(p)	Prior E(p)	Test P	P(p)· Test P	P(p/T=16)	Posterior E(p)
.70	.45	.315	.046	.0207	.157	.110
.80	.30	.240	.172	.0516	.392	.314
.90	.15	.135	.284	.0426	.323	.291
.95	.10	.095	.168	.0168	.128	.122
.99	0	0	.013	0	0	0
	1.00	.785		.1317 = P(T=16)	1.000	.837

Summarizing these results,

Company	Prior E(p) (Percent)	Test Evaluation Results	Favorable Test Results (Percent)	Posterior E(p) (Percent)
X	83.2	2.0325	77.8	77.1
Y	78.5	0.9844	88.9	83.7

Based on this analysis Company Y would still be awarded the contract, but now because the expected value of its performance is higher than that of Company X, and not merely on the basis of absolute formula results with no real way available to make a meaningful comparison. This example shows, then, how it would be possible under a Bayesian approach to combine subjective and sample evidence to make the final result clearer. Prior judgments were in effect reversed in this case as a result of combination with strong contrary sample evidence. In short this case illustrates that Bayesian analysis can serve as a meaningful tool for efficient resource allocation.

In order to be useful, of course, sample evidence needs to be as accurate as possible. This, as has previously been noted, points up an area of weakness in the present DOD-contractor relationship, but one that is receiving increasing attention and hopefully will soon show significant improvement. At present, however, as one DOD official has stated:

> We need better data and better tools for an early assessment of the logistics impact. We can do reasonably well in estimating operational costs, and to a lesser extent production costs. However, our ability to estimate operational and maintenance consequences, including their costs is poor.[29]

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[29] Finn J. Larsen, "ILS-Integrated Logistic Support: Its Necessity and Accomplishment," Proceedings, Integrated Logistic Support Symposium, p. 20.

V

ECONOMIC CONSIDERATIONS IN ILS INVENTORY SUPPORT

> ...the broad outline of a rational inventory policy for spare parts associated with modern weapons is obvious. If the parts are inexpensive stock them in depth and at all locations that need them; we cannot afford to have expensive weapons unavailable for lack of a low-cost part. If, on the other extreme, the parts are very expensive, we will have to get along with a much smaller stock of spares. To prevent expensive weapons from being unavailable because of parts shortages, we must create an information system which detects changes in consumption rates and maintains accurate and up-to-date inventory status records.[1]

Inventory Acquisition and Holding in ILS

In evaluating system alternatives for purposes of making a military choice, it is necessary to be able to assign costs of acquisition and ownership to these alternatives as well as to estimate performance. Acquisition and holding of support inventory is a significant factor in several of the ten designated ILS elements. How well the alternatives involving ILS considerations can be evaluated depends importantly on how accurately inventory elements are valued and

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[1] Zwick, Logistics Modernization, pp. 9-10.

hence the reason for the key position of the logistician. Although accurate determination of the ultimate cost of acquisition has proven to be a problem in the past, the estimation of ownership costs is perhaps even more difficult. Specifically, if the book values of goods in inventory do not reflect adequately their opportunity costs, if procurement procedures are based on faulty concepts of inventory holding costs, or if "protection levels" assigned do not adequately reflect customer needs, then costs assigned to ILS elements might actually be quite misleading when used as a means of helping the decision-maker choose between alternatives. Certainly the cost of ILS itself cannot be properly assessed unless its component elements are properly valued.

The importance of the material acquisition and holding function becomes even more apparent when the previously discussed concept of system availability is considered in more depth. Inherent availability of a system has been defined above as[2]

$$A = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} .$$

In fact, however, the quantity A merely represents a sort of upper limit of potentiality and does not take into account the very real problem of logistics delay. If we can conceive of the idea of a "mean logistics

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[2]As defined in Chapter II, MTBF refers to mean-time-between-failure of a system, and MTTR stands for mean-time-to-repair.

dealy" time (MLD), then the true operational availability that can actually be obtained is

$$A_o = \frac{MTBF}{MTBF + MTTR + MLD} .$$

The effect of MLD can be seen in the estimate of one company that new, sophisticated systems are available for operational use in the field (Up Time) less than 50 percent of the time due to logistics delay.[3] This same company has estimated that inherent system availability (A) can be divided in the following manner:

Component	Percent of Total System Time
Up Time	40
Repair Time	1
Logistics Delay	59
	100

The primary system problem, thus, is one of supportability. Further, the relation of operational costs to total system cost has also been estimated as follows:

Components of Total System Costs	Percent of Total System Costs
Procurement	31
R & D	6
Pay and Allowances	29
Operation and Maintenance	34
	100

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[3]Raytheon Company, Life Cycle Costing Implementation (Lexington, Mass.: Raytheon Company, n.d.), pp. 4-5.

Here total operational costs are the sum of pay and allowances and operation and maintenance expenditures. Logistic support costs, in turn, comprise a significant portion of these elements.

Maintenance of high operational availability depends on having the right material when and where needed. This means that decisions are constantly required as to the appropriate range and distribution of spare parts and other items of inventory. Decisions as to the material to be carried and costs assigned thereto are of considerable importance to the ILS manager first because the sheer quantity of material in inventory has a financial impact, and second because of the importance of mix considerations. If the physical level of support inventory is increased, a reduction in MLD and an increase in Up Time should result. Such action will, however, increase the cost of various ILS support elements and hence ILS itself unless offsetting reductions are elsewhere realized. A tradeoff situation is thus presented to the logistician. The range, or mix, of items carried in inventory is influenced by the holding costs involved as is the quantity of individual items carried. Current military and in particular, Naval logistics concepts and procedures dealing with these issues may at present be too narrow in scope. This may then result in less than optimal decisions being made and courses of action followed.

The Function of Inventory Management

Business logistics, as differentiated from military logistics, is composed of the functions of movement control (traffic and transportation and warehousing and materials handling) and demand-supply coordination (order processing and information flow, inventory management and supply scheduling and allocation).[4] ILS, as has been noted, does not include the same elements. Common to both business logistics and ILS, however, is the important function of inventory management. Certain aspects of this important element are therefore considered at some length below in an effort to indicate how some of the newer concepts of business logistics as well as established economic principles might be interjected into ILS procedures as an aid to decision-making.

The components of cost in inventory. -- One writer has pointed out that there are essentially two different types of costs associated with business inventories -- acquisition costs and possession costs -- and that an important aspect of logistics management is to make economic trade-offs between them.[5] The military logistician is faced with much the same problem; that is, the necessity to aim for

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[4]See Heskett, Ivie, and Glaskowsky, Business Logistics, p. 22.

[5]Dean S. Ammer, Materials Management (Homewood, Ill.: Richard D. Irwin, Inc., 1968), pp. 239-242.

an inventory policy which will minimize the total of all support and acquisition costs consistent with the level of system availability designated (this level is here assumed to be analogous to the business concept of customer service level (CSL).

For purposes of this study, total inventory costs may be divided into the following categories:

1. Unit acquisition cost. This represents the ultimate purchase price of the logistics support items. Quantity and range of material purchased for inventory depends largely on cost, needs of the customer, and level of system availability required. In the terminology of Navy inventory management, the inventory "protection level" selected to provide a certain CSL is thus highly influential.[6] Economic order quantity (EOQ) formulas are in use for the selection of order quantities, considering these as well as other factors.[7] (More will be said below about certain

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[6] The derivation and use of "protection levels" in Navy inventory control are discussed in more detail infra.

[7] EOQ refers to that order size which theoretically results in the lowest cost per unit of inventory, acquisition and ownership factors considered. One of the oldest recognized EOQ formulas was developed at Yale and is known as Camp's formula. It can be stated as:

$$EOQ = \sqrt{\frac{2RS}{KC}}$$

where EOQ = the economic order quantity
R = annual rate of usage
S = cost of placing an order (or setup costs if manufactured)
C = standard cost per unit, and
K = percentage of total inventory value spent annually to maintain inventory.

of these EOQ procedures.) Once an order size is determined by economic order or other procedures, acquisition cost of inventory items can normally be fairly closely estimated, at least once the research and development stage has been completed.

2. Ordering and reordering cost. This measures those relatively fixed steps involved in placing an order and preparing to receive it. Some costs in this category may vary with size and frequency of the order, but these costs are a small portion of the total.

3. Shortage cost. This is a measure of the loss which would occur if a particular item of Supply Support should not be available when and where required. It includes the costs of priority ordering and premium shipping. Theoretically it should also account for loss of availability of the system requiring support.

4. Holding or carrying cost. This component which includes outlay as well as opportunity costs of holding inventory has been estimated by a number of business logisticians as amounting to about 25 percent per year of the average value of inventory carried.[8] The well-known Alford & Bangs allocation of this

[8]Heskett, Ivie, and Glaskowsky, Business Logistics, pp. 13-14 and 269. See also G. B. Carson, ed., Production Handbook (2nd ed.; New York: The Ronald Press Company, 1958), pp. 4, 56-69, and Ammer, Materials Management, p. 239.

total is:[9]

Component	Percent of Average Inventory Cost per Year
Storage Facilities	.25
Insurance	.25
Taxes	.50
Transportation	.50
Handling and Distribution	2.50
Depreciation	5.00
Interest	6.00
Obsolescence	10.00
	25.00

This breakdown is one of few such listings published and while issue might be taken with the exactness of some of the individual item estimates, at least this work does provide an authoritative frame of reference based on research into the subject. Certainly, the 25 percent figure seems to be fairly widely accepted. That total inventory carrying costs are very important in the private economy can be seen in the fact that they annually comprise as much as 6 percent of the country's Gross National Product.[10] Surely then these costs must also be of major concern in military logistics. In the private sector the size of inventories is of continuing concern because if they are too

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[9] L. P. Alford and John R. Bangs, eds., Production Handbook (New York: The Ronald Press Company, 1955), pp. 396-397.

[10] Heskett, Ivie, and Glaskowsky, Business Logistics, pp. 14-15.

large, the firm's profitability will be reduced.[11] This same sort of reasoning can also hold in the case of military inventories, the existence of which represents foregone opportunities to utilize appropriated funds in other ways -- another application of the concept of opportunity cost. The very minimum opportunity costs of inventory investment to a private company might be considered to be the earning potential lost because of non-investment in riskless short-term government securities. In point of fact such costs should also not be overlooked or minimized in the military. Secretary of the Navy Instruction 4000.20 for example, specifically charges the Chief of Naval Material with responsibility to:

1. Develop and prescribe procedures for the prediction of logistic support costs [which should include inventory carrying costs].
2. Develop and prescribe procedures for optimizing logistic support costs....

In light of the foregoing, then, the remainder of this chapter will focus in particular on the inventory carrying cost components of inventory, obsolescence and depreciation, and on the system availability or reliability level, which here can be considered the military equivalent of the business concept of customer service level, as these con-

[11] Of course if inventories prove too small, demand will not be adequately satisfied. This problem is considered _infra_ in the discussion of customer service levels.

siderations concern the material elements of ILS and hence decision-making involving allocation of resources.[12]

Treatment of Interest Costs Involved in Holding Military Inventory

The rate of interest can be conceived of as serving two separate and distinct functions in inventory management. In the first place, in its "pure" form, it provides the means whereby the present value of costs and benefits can be obtained (see Chapter III for a more detailed discussion of the process of present value discounting as it effects ILS). As one writer has noted, "The technique of discounting future costs and benefits in order to obtain their present value is an accepted method of converting a multi-period problem to a static problem in investment theory."[13] This value theoretically reflects the prevailing "cost of capital" and is influenced by the time preference of the decision-maker. Determination of this rate, however, has some interesting aspects. For instance, it must be clear as to how the term

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[12]This chapter deals with topics which fall under the general heading of inventory control. This term is defined in Joint Chiefs of Staff, Dictionary of U.S. Military Terms for Joint Usage, pp. 115-116, as "That phase of military logistics which includes managing, cataloging, requirements, determination, procurement, distribution, overhaul, and disposition of material." Such is the sense in which the concept is used in this study.

[13]Donald R. Stone, Discounting in Military-Cost-Effectiveness Studies (unpublished Master's Thesis, United States Naval Postgraduate School, 1965), p. 1.

cost of capital is being defined. One important study of this problem, for instance, concluded that the pure interest cost applicable to government investment should be about 15 percent.[14] The reasoning, similar to that discussed above, is that government capital investments which would include military inventory involve opportunity costs. These costs are said to be best measured by the rate of return obtainable before income tax in private industry -- manufacturing, in particular. For the period 1949-1958, the average annual rate of return of representative manufacturing corporations before income tax was found to be 19.6 percent. During the period 1961-1965, the rate was 15.4 percent.[15] The basic principle involved here is followed in this study. When the government invests in inventory, it prevents the resource allocation decision from originating in the private sector. Such resources, if otherwise freely available would theoretically have tended to channel themselves toward the then most profitable segment of the economy. Thus the use of some sort of average or marginal rate of return, often used as a measure of opportunity cost, might

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[14] J. A. Stockfish, The Interest Cost of Holding Military Inventory (Los Angeles, Calif.: Planning Research Corporation, May, 1960), pp. 1-5.

[15] For more detail see the statement of J. S. Stockfish in U. S., Congress, Joint Economic Committee, Planning-Programming-Budgeting System: Progress and Potentials, Hearings, before the Senate Subcommittee on Economy in Government, Joint Committee Print (Washington, D. C.: Government Printing Office, 1967).

actually be biased on the low side. Return before income tax is accepted as an appropriate measure since it tends to reduce the influence of certain non-economic factors and hence more adequately defines the ability of a firm to meet consumer wants and needs. This reasoning, of course, assumes a condition of relatively full employment in the economy, a goal likely to be generally desired by both political parties.

The private sector has historically made earlier and more frequent use of the technique of discounting than has government in general and, in particular, the Department of Defense. A research paper on this subject, in fact, has stated that "While industry has developed discounted return on investment methods, DOD test procurements have merely added up the costs and awarded on the basis of lowest total cost. The Government could learn from industry experience in this particular area even though the objects of profit maximization and cost minimization are different."[16] DOD has made use of discounting in its cost-effectiveness studies. (This subject is discussed further in Chapter VI.) The procedure, however, remains yet to be effectively implemented in the area of logistics support.

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[16] Logistics Management Institute, Life Cycle Costing in Industry (Washington, D. C.: Logistics Management Institute, September, 1967), pp. 11-12.

Allowance for risk. -- Discussion thus far has centered about the idea of a "pure" interest rate to be used in discounting operations in relatively risk-free situations. Such, however, is not truly characteristic of military investments in general. Risk is ever-present in new system investment, including related support functions. Indeed, it is probably greater than in the private sector of the economy. Some reasons which have been suggested for this include:[17]

1. The possibility that war might break out sooner than expected, before capability is achieved, and hence investment in effectiveness already made might never be utilized.
2. The possibility that peace might be realized, or arms limitation agreements reached, rendering many military systems either unnecessary or unuseable. Here again no realization would be obtained from investment made.
3. The possibility that final performance of new, highly sophisticated systems might not be acceptable, despite the expenditure of large sums of development and procurement funds.
4. The possibility that the general political climate might change quite rapidly, causing unanticipated changes in deployment, and hence in required support inventory.

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[17] Hitch and McKean, The Economics of Defense in the Nuclear Age, pp. 205-218 discusses in more detail the issue of risk and time considerations in military investment.

5. The fact that costs of military systems have experienced wide variations, chiefly upward, from original estimates. In some cases, this has made necessary the acceptance of a lower level of capability.

Some additional amount must therefore be added to the pure rate of interest to allow for the element of risk involved.

The point has thus been made that the use of either an average or a pure interest rate to reflect the cost of capital (including inventories) may not be sufficient in the military environment. To arrive at a suitable rate of interest for military decision-making purposes, therefore, two elements must be evaluated and combined. These are:

1. The "pure" rate of interest reflecting time preference, and
2. An additional allowance for risks unique to the military situation.

With this discussion in mind, then, it would now be appropriate to inquire into discounting procedures followed by various Federal agencies and to consider what implications are thereby involved for ILS.

<u>Discounting practices in Government.</u> -- In January, 1968, the Controller General of the United States submitted a report to the Joint Economic Committee of the Congress. This report presented the results of a General Accounting office survey of general discounting

practices used by some twenty-three Federal agencies.[18] A wide range of practices was revealed, with rates utilized ranging from 3 percent upwards to 15 percent. Thirteen of the twenty-three agencies reported that they did not use discounting at all. Of the ten which did, the primary reason for the difference in rates chosen was the fact that one group of agencies held that the rate should be determined by and be equal to the rate paid by the Treasury in its borrowing operations. The other group held to the general concept of private sector opportunity cost. Within each group, however, significant differences were also apparent as to the appropriate rate to be used. A summary of rates used by the ten agencies together with supporting rationale is included as Appendix I.

The Department of Defense reply stated that a 10 percent discount rate was used, but only in its military construction program. This rate was felt "to reflect the amount of time preference for current versus future money sacrifices that the public exhibits in non-governmental transactions. The 10 percent rate is considered to be the most representative point within a range of plausible rates ob-

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[18]U. S., Controller General, Report to the Joint Economic Committee, Congress of the United States, Survey of Use By Federal Agencies of the Discounting Technique in Evaluating Future Programs (Washington, D. C.: U.S. General Accounting Office, January 29, 1968).

tained from considering the public time preference."[19] It was furthere pointed out that this rate was used for construction projects at shipyards and other naval establishments. At no point in this document is mention made of use of the interest rate for discounting inventory costs.

Choice of an interest rate to discount capital costs and benefits has important implications for resource allocation. When various Federal agencies use different rates, it is obviously impossible to make inter-agency comparisons. If two agencies use different rates, programs of the agency using the lower rate will tend to show a more favorable cost-benefit ratio thus leading, potentially at least, to resource misallocation. (See Chapter VI for a further discussion of this point.) There is therefore a need for general guidance in this area to be supplied by the Congress, especially in view of the adoption of the Planning-Programming-Budgeting System within the government (see the discussions concerning PPBS in Chapter II and cost-benefit analysis in Chapter VI).

But this is a larger problem than can be dealt with in this study. Rather what is to be evaluated here is the procedure followed specifically by DOD. The GAO report referred to above pointed out that DOD applied the 10 percent discount rate only to certain construction projects.

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[19] Ibid., p. 22.

Department of Defense Instruction 7041.3, subsequently issued, confirms this policy. The supposed intent is to adopt an interest rate which "reflects the private sector investment opportunities foregone."[20] Such rate has been determined by DOD to be 10 percent. Of particular importance for this study, however, is the fact that the instruction specifically excludes from economic analysis "proposed acquisitions of principal or secondary items, justified on the basis of an inventory objective in accordance with DOD logistic guidance." Investment in inventory is thus not to be considered as a capital cost in the same way as would be a construction project.

Navy Inventory Policy

The development of DOD and Navy inventory policy is an outgrowth of the annual budget process in which the Secretary of Defense issues logistics guidance to the Services in the form of a "Draft Presidential Memorandum." This document spells out planning objectives related to: (1) forces to be supported in the event of mobilization; (2) amount of material to be procured to support these forces; and (3) level of peacetime support for existing forces.

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[20]U. S., Department of Defense, Instruction 7041.3, Economic Analysis of Proposed Department of Defense Investments (Washington, D. C.: Assistant Secretary of Defense (Comptroller), February 26, 1969).

Within these broad guidelines, each military service develops its own interpretations and guidance to lower levels. In the Navy, supply system responsiveness requirements are specified by the Chief of Naval Operations and carried out by the Naval Supply Systems Command (NAVSUP). Under NAVSUP individual inventory managers such as the Aviation Supply Office, Electronics Supply Office, and Ships Parts Control Center must then decide how to allocate limited resources over all items in the inventory under their cognizance in some manner so as to obtain the best possible return from the capital investment involved and to insure support for items of high essentiality.

These inventory managers, of course, support the Navy's Material System Commands and Project Managers through the provisioning of new weapons systems and equipment and the maintenance of inventory. To assist in performing this task efficiently decision rules have been developed within the Navy whose purpose is to arrive at an optimal position by balancing acquisition costs, holding costs and shortage costs. For the present it is assumed that acquisition costs have been determined. Shortage costs are considered together with the general topic of customer service levels and are so discussed below. What remains here to be looked at then is the subject of holding cost policy and procedure.

<u>Holding cost policy.</u> -- In 1958 the Department of Defense promulgated an instruction whose purpose was to "establish a policy for peacetime operating and safety levels of supply on the most economical basis considering military necessity, item activity and other item characteristics and supply operating costs."[21] This instruction put forward the notion of economic order quantity and also detailed elements of holding cost which, as a minimum, were to be taken into consideration by inventory managers. These minimum cost elements were listed as interest on dollar investment (which for the purposes of the instruction was arbitrarily set at 4 percent); obsolescence, deterioration and shrinkage, required stock and financial control, care and preservation of stock, storage, and physical inventory.

The importance of the above for the present study is that:

1. Navy decision rules still generally use the 4 percent interest rate figure in inventory matters whereas 10 percent has been specified for certain other capital investments, as noted above.
2. Holding cost, for purposes of a number of current decision rule computations pertaining to consumable standard items

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[21] U. S., Department of Defense, Instruction 4140. 11 <u>Peacetime Operating and Safety Levels of Supply</u> (Washington, D. C.: Assistant Secretary of Defense (Supply and Logistics), June 24, 1958).

in inventory, is assumed to be a constant, usually amounting to 15 percent per year per dollar of inventory and normally composed of three elements as follows:

Component	Percent
Interest	4
Storage	1
Obsolescence	10
Total	15

Provision is made, however, in some cases for varying, within limits, the rate of obsolescence used. In such cases, a linear discount rate is used for obsolescence, i.e., an item with an estimated five year life would have an obsolescence rate of about .20 signifying a loss of 20 percent of its value per year.

The holding cost rate selected can, of course, significantly affect EOQ decisions. DOD Instruction 4140.11, as noted above, specified that the economic order principle should be applied in the following form:

$$Q = \sqrt{\frac{2AC}{H}}$$

where:

Q = the economic order quantity in dollars

A = the annual value of demand in dollars

C = the cost to order in dollars, and

H = the cost to hold expressed as a percentage per year.

A standard commercial formula of the same general type although not equivalent produces a quantity result expressed in units by introducing price per unit (P):[22]

$$Q = \sqrt{\frac{2AC}{HP}} \ .$$

Such formulas make a number of simplifying assumptions, including demand certainty and no restriction on order size.[23] More complex formulas have therefore been developed, both in industry and in the DOD, to deal with these complications.[24] The purpose

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[22]For the derivation of Camp's formula, see George N. Collins, "Advanced Techniques in Production and Inventory Control," in Readings in Physical Distribution, ed. by Hale C. Bartlett (Danville, Ill.: The Interstate Printers & Publishers, Inc., 1968), p. 73.

[23]A typical Navy order quantity formula of this type is one now used at certain activities for standard repairable items:

$$Q = \sqrt{\frac{8(D-B)A}{(i+s+a)c}}$$

where: D = quarterly demand at end of lifetime
B = quarterly recoveries from repair
A = cost to place an order
i = interest, or time preference rate
s = storage rate
a = obsolescence rate
c = unit price

[24]For example, see the models developed in Bierman, Bonini, and Hausman, Quantitative Analysis for Business Decisions, pp. 169-179. Also, Naval Supply Systems Command, Navy Implementation of DOD instruction 4140.11 (Washington, D.C.: Research Analysis Staff, July 31, 1968), various pages.

here is not to delve into the derivation of such formulas, but rather to point out that techniques are readily available for extending EOQ principles to take into account special circumstances such as minimum order level and variable demand, and also that the basic EOQ form discussed above is appropriate to consider since it is presently used with some variation by Navy inventory managers. The value set for H, cost to hold expressed as a percentage per year, is obviously quite important, and interest rate is a significant component of H. If this rate is set arbitrarily at too low a level, the buy quantity and total inventory level held will be increased, thus wasting resources.[25] Similar reasoning holds for other elements of holding cost as well.

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[25]It should be stated at this point that no single, uniform set of rules exists in the Navy which provides general guidance on stock levels and order quantity determination for all commodities. In dealing with the problem of demand variation, however, the statistical concept of mean absolute deviation (MAD) is often used. Sometimes it is used in calculation of an estimator of the standard deviation of demand for an item whose leadtime demand is distributed $N(\mu, \sigma^2)$. The standard deviation of the i^{th} item in terms of absolute deviation in items per quarter is then shown as

$$\hat{\sigma}_i = \sqrt{\frac{\pi}{2}}\ MAD_i \ .$$

In another usage, standard deviation is derived from

$$\sigma = \frac{1.25}{\sqrt{3}}\ (MAD)\ \sqrt{L}$$

where L = Leadtime (see footnote 37). In still other cases, MAD itself is used directly as a measure of variation of demand. Yet MAD does not have nice statistical properties when dealing in probabilities. For instance, $MAD_x + MAD_y \neq MAD_{x+y}$. A nicer measure of dispersion would be the variance (VAR), where $VAR_x + VAR_y = VAR_{x+y}$, assuming statistical independence. The standard deviation of demand

Obsolescence, storage rates and depreciation. -- Determination of a value for rate of obsolescence is also of extreme importance since it is potentially the largest single component of inventory holding cost. A value commonly used in the Navy for an obsolescence rate has been noted as being 10 percent of average inventory value, with some flexibility for upward adjustment. In theory, the relationship is obsolescence rate (in percent) = $\frac{1}{\text{Estimated Shelf Life in Years}}$ x 100. Thus when an item has become completely obsolete this fraction becomes infinity, H becomes infinite and Q becomes zero. In practice, however, 10 percent is often adopted as a sort of general rule of thumb. Inventory obsolescence, including spoilage, can take several forms in private industry, including:[26]

1. Outright physical deterioration over a period of time.
2. Risk that a particular item in inventory will:
   a. become technologically unusable, or
   b. go out of style.

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could then be quickly estimated directly from $\sqrt{VAR_x}$ where $E(X - \mu)^2 = VAR_x = EX^2 - (EX)^2$. MAD simply weighs differences from the mean whereas VAR weighs differences by probability times the deviation. In any event, the three basic techniques used in demand forecasting are moving average, single exponential smoothing and double exponential smoothing.

[26]For more detail, see the discussion in John F. Magee, "Guides to Inventory Policy," Harvard Business Review, January-February, 1956, p. 6.

In specific reference to inventory supporting modern military systems, item 2a above must be considered the prime factor in obsolescence. Indeed, one writer has noted that "...as we modify our systems we obsolete a segment of our spare parts inventory."[27] In this connection a report which discussed inventory holding costs both in private industry and in the military concluded that "...the risk of obsolescence is, in general, much higher than is the case in private industry."[28] Certainly this trend has only continued to intensify in recent years. Speaking before the Senate Foreign Relations Committee, for example, Dr. Herbert York, formerly in charge of DOD research, stated that the complex, costly and highly sophisticated Anti-Ballistic Missile system could be rendered obsolete in as few as 10 years.[29] Inventory managers have often in the past greatly increased the quantity of spare parts in stock to completely insure that an equipment would never be idle for lack of a part. A study of cruisers and destroyers in the Atlantic Fleet, for instance, once showed that 85 percent of items carried in inventory on the ships were

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[27]Zwick, Logistics Modernization, p. 4.

[28]Logistics Management Institute, Life Cycle Costing in Equipment Procurement, p. 38.

[29]U.S., Congress, Senate, Strategic and Foreign Policy Implications of ABM Systems, Part III, Hearings, before a subcommittee of the Committee on Foreign Relations, 91st Cong., 1st sess., 1969, p. 674.

never used from overhaul to overhaul.[30] The high cost and risk of obsolescence of spare parts associated with modern weapons systems has made this policy no longer tenable. Obvious also is the fact that standard consumables simply cannot be treated in like manner for inventory management purposes if one item specifically supports a weapon system and another is entirely a common-use end item.

It may be recalled that the Alford and Bangs computation of holding cost included depreciation at 5 percent of the average value of inventory per year and storage at .25 percent. In Navy EOQ formulas, storage is often included at 1 percent. It would seem reasonable that this rate should be higher in the case of military inventory since the range and quantity of items carried and facilities and personnel required in management capacities are much larger than is the case in private industry. As for depreciation, however, no charge is generally made separate from the charge for obsolescence. Granted that it is difficult to identify the incremental quantities of many resource services associated with logistics support in general and inventory maintenance in general. Yet it seems that some attempt should be made to consider depreciation separately. Speaking specifically of certain revolving fund logistics support enterprises such as the Defense Supply Agency, one writer notes a weak-

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[30] Worden, "Integrated Logistics Support," p. 21.

ness which he considers quite serious is that "The current account has no entry for depreciation. . ."[31] In the past losses have occurred in the value of the revolving Navy Stock Fund because prices charged for issues out of inventory were not high enough to cover material losses caused by such losses as inventory shortages and deterioration or depreciation.

The above discussion supports the conclusion that military inventory holding costs are significantly understated and the ILS logistician therefore does not have available, in many instances, figures which represent the true capital costs of the alternatives he is considering. Consider first the element of interest rate. Originally, 4 percent was apparently selected because this was approximately the rate the government actually paid on long-term borrowing. This certainly is not the case today.[32] Supposedly, this rate was considered to be a measure of the "cost of money" which all Federal agencies could use. This 4 percent rate is <u>not</u>, however, a valid measure of cost of money to the government. Nor, in fact, is any rate which merely reflects the discount on long-term Treasury bonds.

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[31] Bailey, "The Market Mechanism in the Defense Department," p. 178. He states that if all items were included that are accounted for in conventional bookkeeping, revolving fund enterprises would comprise more than 20 percent of annual DOD resource use.

[32] For instance, on October 27, 1969, the long-term Treasury bond rate was listed in <u>The New York Times</u> at 6.2 percent.

As previously mentioned, funds tied up in public capital projects theoretically do add in some fashion to the total productivity of the economy. The question, then, is are these funds being used in the most efficient manner in an opportunity sense. Comparison with the rate of return before taxes in the private sector would seem to be a more appropriate measure of this efficiency.

Not only is the Treasury long-term bond rate inappropriate as a measure of the opportunity cost of money, but it has also been pointed out that the use of an inappropriately low rate may result in buying quantities that are too high, economically speaking, leading to overinvestment in inventory. It may be that high weapon system support inventory levels are justified for reasons of national security. If so, sufficient funds should be allocated to permit procurement based on a more realistic approach to the opportunity cost of capital. That the average rate of return actually realized in the private economy is probably, in fact, a conservative approach is indicated in the opinion expressed that "When inventory...is normally financed internally (author's italics), a rate of return or imputed interest rate between 10 and 30 percent is not unreasonable."[33] It has also been pointed out in this regard that "The cost of borrowing new capital is

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[33]John F. Magee and David M. Boodman, Production Planning and Inventory Control (2nd ed.; New York: McGraw Hill Book Company, 1967), p. 48.

apt to be misleading for estimating the cost of capital in inventory unless the firm [or government agency] is actually willing to increase or decrease its borrowing [or budget request] in response to inventory changes."[34] In the case of military inventories such a course might be practically as well as politically impossible. Some investments are riskier than others, and this must be recognized in the discount rate selected. And certainly "Advanced weapon systems... appear to be among the riskiest enterprises of the modern world."[35] This risk should be recognized separately from the pure discount rate.

Once a risk is somehow evaluated, it can be combined with the utility function of the decision-maker. This presents an opportunity for a Bayesian approach to this matter of interest rate selection. An inventory manager can select a particular rate of interest based on his knowledge of economic activity and the riskiness of the investment. This rate could then be updated as more information is received, thus permitting changes in the range and level of inventory to be made in a rational manner. The real problem, however, in

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[34] Charles C. Holt, et al., Planning Production, Inventories and Work Force (Englewood Cliffs, N.J.: Prentice Hall, Inc., 1960), p. 71.

[35] Hitch and McKean, The Economics of Defense in the Nuclear Age, p. 210.

setting a realistic inventory goal is in obtaining the manager's policy statement. Once this is obtained, arbitrary factors should be replaced to as large an extent as possible with decision rules resting on a sound economic base.[36] This applies to the handling of obsolescence and depreciation as well as the interest rate.

As one final comment on the treatment of holding costs, mention should be briefly made of the method of treating items newly placed into inventory. Increasingly, these are consumables which support new systems and hence are highly subject to obsolescence. The percentage of such items in total Navy inventory stocks seems certain to increase. The ability should thus exist to permit an estimation of holding costs for new items at various rates. Yet at least as late as November, 1968, the Navy was using in contracts ranging up to a billion dollars <u>a predetermined fixed cost</u> per inventory line item for carrying costs, regardless of commodity, inventory control point, federal stock class, investment cost, or any other variable. In view of the preceding discussion, it would seem that such policy should be reviewed on general economic grounds.

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[36]One Navy EOQ formula, for instance, does define order quantity as $Q = \max \left\{ \text{unit pack, one month's supply, } \min \left\{ \begin{array}{l} Q \\ \text{Shelf life} \\ \text{Technical life} \end{array} \right. \right.$

There is, however, little evidence that obsolescence is realistically taken into account in all cases in the determination of technical life.

Customer Service Level Considerations in ILS

In his role of providing economically efficient operational support to military systems, the logistician faces a number of internal and external constraints on his activities. One of the most important of these occurs in the area of inventory control and centers around the level of service that has been decided on by inventory managers as necessary to meet customer requirements. Potential loss which could be realized as a result of insufficient service is an important factor in deciding what should constitute an adequate inventory policy. In private business a firm might establish a particular level of sales or orders satisfied which it would be prepared to meet with virtual certainty from existing or nearly-on-hand stock. The firm, then, would be willing to settle for the loss of sales which might result should this level be exceeded. In a sense, military logistics faces a similar problem. Navy inventory managers, for instance, determine "protection levels" desired for various classes of commodities in inventory. A protection level of 95 percent would mean that there is a 5 percent chance of stock-out during the demand period.

Safety levels of stock are established in order to provide planned protection levels during procurement lead time periods. These safety levels are computed by multiplying expected deviation in demand over lead time by a factor representative of the protection

level established for the items.[37] Generally, an item is placed in a "sales class" and every item in the class is afforded the same protection. The procedure is that the protection level desired is first determined, and then the number of units that would supply that protection is calculated and planned for. Budgetary limitations may, of course, force some changes to be subsequently made.

Desired protection levels are in part set as a result of stratification requirements and the assignment of essentiality codes to some items in inventory. Stratification is a process prescribed by the Assistant Secretary of Defense and performed by all Navy inventory control managers whereby inventory requirements are arranged in order of priority and available assets applied against them. If assets are less than requirements, then stock fund increases are requested in the normal budgetary procedure. A number of measures of effectiveness have been devised to help the inventory manager assess the results of his policy actions. Among these measures

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[37]Safety level of stock in the Navy is commonly derived from a normal curve concept and recognizes the need to plan for leadtime demand.

are statistics relating to number of items short, number of orders unfilled, and dollar value of items short or orders unfilled. Military Essentiality Codes are arrived at for various items as a result of information provided by the responsible Systems Commands and Project Managers (See Appendix B).[38]

The protection level process is based on an assumed normal distribution of demands, and at times seems more designed to protect the inventory manager than the ultimate consumer. The customer, a system logistician in this instance, cares very little about how well the inventory manager is able to make manipulations so as to remain within prescribed investment and workload constraints. He is interested rather in whether or not an item is available when needed to support a critical system. In this context, customer service levels in support of a critical military system are similar in nature to service levels within a business firm, where the firm's production line is the ultimate customer. Referring to such a situation, it has been stated that "If the production line is the customer,

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[38]The determination of an item's essentiality code, or weight, is a complex task and involves the utilization of all available expert maintenance and operational judgment. Among pertinent considerations in the determination are:

1. Criticality of the system's mission.
2. Importance of the part or component to the mission, and
3. Degree to which the item's non-availability could be compensated for.

an out-of-stock situation may be intolerable. Cause is often hard to trace. These reasons make the out-of-stock measurement largely an academic exercise."[39] There is virtually no cost involved in physically supplying the needed item which could exceed the cost of shutting down the production line, or, in the ILS context, rendering a costly, highly critical system inoperative. When items that support such systems are assigned to inventory classes for which overall protection levels are decided on, in part based on budgetary considerations, then there is a strong possibility that support may not be supplied when needed most. Items are generally ordered and stocked based primarily on expected demand, with criticality or essentiality being only one of a number of other factors considered.[40] Demand is customarily reviewed quarterly in order to revise order quantity and reorder levels. Nevertheless, more flexibility is required by inventory managers to determine protection levels on an item by item basis in the case of critical system support inventory of a consumable nature. It is true that procedures do exist to esti-

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[39]Heskett, Ivie, and Glaskowsky, Business Logistics, p. 165.

[40]A general replenishment rule at Navy inventory control activities for consumables is: If inventory (on hand and on-order) drops to some pre-determined reorder level, then order sufficient stock to bring item inventories up to a "desired" level, which is usually the sum of the reorder level, the economic order quantity, and any authorized set-asides as, for instance, war reserves.

mate the economically acceptable risk of being out of stock. Figures used in this computation, however, come as a rule from a "requisition shortage cost" which is calculated for an entire cognizance symbol covering many items. This shortage cost is often calculated as the number of units short (i.e., not in stock) per year times the importance (essentiality) of the unit times the cost of being out of stock of one item of unit essentiality. This latter cost is considered as arising from the necessity for premium ordering, expediting, and transporting.[41] No calculation is made of a shortage "penalty" which would result from potential down time of the supported system. The point is that these calculations may be, as noted above, largely academic exercise in any event, particularly in the case of highly critical systems, in terms of national defense needs.

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[41]Using this shortage cost figure, the risk involved is sometimes calculated as

$$\text{Risk} = \frac{(H)(C)(Q)}{(4D)(S)(E)}$$

where: H = holding cost
C = unit price
Q = basic order quantity
D = average quarterly demand
S = shortage cost
E = essentiality

Thus in the case of an item whose unit price is $4, holding cost the typical 15 percent, shortage cost $15, basic order quantity 60, average annual demand 15, and unit essentiality, we would have

$$\text{Risk} = \frac{(.15)(4)(60)}{(4)(15)(15)(1)} = .04 \text{ or } 4 \text{ percent.}$$

Another point concerning the determination of protection levels for various classes or even items of stock is that this should be done only on the strength of the results of analysis of the comparative costs of possible and feasible logistic supply systems.[42] Costs of the variable components in these systems need to be compared, such as order transmittal mediums, order processing procedures, material handling and packaging, warehousing, and modes of shipment. The most economical method of providing a protection or service level can be properly found only by trading off one type of cost for another, rather than accepting a particular logistics system as "set" and deciding on protection levels based on it. These protection levels should not be set, as is now frequently the case, independent of a consideration of the elements of logistic cost involved in providing that standard. The logistician as well as the ILS Supply Support element inventory manager need to be concerned with more than simply the cost of the support material. The total support system must be evaluated in the interests of efficient resource allocation. Shortening the requisition cycle, for instance, could be a key element in reducing overall logistic costs.

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[42] See, for example, Heskett, Ivie and Glaskowsky, Business Logistics, pp. 172-175 for an example of a typical procedure for calculating the "profitability" of various service levels under alternate logistics systems.

Policy of Navy inventory managers as concerns systems consumable support should be kept as flexible as possible with provision for considering critical material on an item by item basis. It has been noted that "Stockage policy has a pervasive, if implicit control over the [logistic] systems operating costs: It determines the level of investment and frequency of shortages, of requisitions, of new procurements, and of repair actions."[43] A Bayesian process could conceivably provide a more systematic method of realizing a greater degree of flexibility based on experience. Thus probabilistic calculations of expected demand rates could be made and then combined with subjective probabilistic estimates of the inventory managers. The resulting posterior distribution could then be updated periodically based on actual demand experienced during that period. The mechanical process could be similar to that previously discussed in Chapter IV.

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[43]Harrison S. Campbell, "Procurement and Management of Spares," in Defense Management, ed. by Enke, p. 187.

VI

THE ROLE OF COST-BENEFIT ANALYSIS IN ILS

> . . . some significant consequences of public undertakings must, it seems, always elude the craft of the quantifier. Nevertheless, the process of political decision can be sharpened significantly by removing as many aspects as possible from the realm of unsupported opinion and emotic rhetoric.[1]

Definition of Cost-Benefit Analysis

Cost-benefit analysis as used in this study has been defined as ". . . a systematic examination of the benefits and costs of a particular governmental program, setting out the factors that should enter into the evaluation of the desirability of the program and frequently analyzing several alternatives for the attainment of the objective."[2] Elements of the analysis include:

1. A statement of the objective, or goal to be attained.
2. A statement of the alternatives (or "systems") which it is anticipated should be able to achieve the objective or goal.

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[1]Robert Dorfman, ed., Measuring Benefits of Government Investment (Washington, D. C.: The Brookings Institution, 1965), p. 2.

[2]Due, Government Finance: Economics of the Public Sector, p. 62.

3. A statement of the costs (if possible in terms of opportunities foregone) and benefits, direct and indirect, which may be expected to result from the adoption of each alternative.
4. A model which shows the relationships among the variables involved.
5. Criteria by which alternatives are ranked and on the basis of which the most promising is chosen.

Inasmuch as cost-benefit analysis involves the comparison of a stream of costs and a stream of benefits accruing from each alternative, both streams discounted back to present value, a simple mathematical model for use in this comparison might be formulated as

$$\sum_{t=1}^{n} \frac{B_t}{(1+r)^t} - \frac{C_t}{(1+r)^t}$$

where B = the stream of benefits
C = the stream of costs
r = the discount rate
n = the life of the project
t = year of occurrence of the cost or benefit

Once having decided on objectives and criteria for determining benefits, that alternative method for accomplishing a particular program would then be considered "best" which showed the highest positive value. Given an unlimited budget, all programs would be pursued which could show at least one acceptable alternative with a computed value no less than zero. Another way of expressing this would be to

say that the benefit to cost ratio should be at least equal to one. Since unlimited budgets are rarely the case in government, however, the constrained budget will theoretically be allocated to programs which appear to promise relatively greater excesses of benefits over costs. In this context, cost-benefit analysis is similar to capital budgeting procedures used by businessmen in the private sector. The main difference is that some sort of social value must be established in the place of market value.

Significance of the interest rate. -- In economic analysis, the interest rate selected for discounting is important. Many projects, for instance, might show a positive net present value at a discount rate of 4 percent, but not at 10 percent. In the event that program managers use different discount rates in evaluating alternatives or ranking programs, and do so without strong justification, then resource misallocation can easily result. Consider a case, for example, where a program manager faced with budget limitations is trying to decide which of two programs to include in the budget for the coming fiscal year. Assume that the analyst evaluating Program A uses a discount rate of 4.5 percent while the Program B analyst does not use discounting at all. Each program is estimated to have a twenty-five year life cycle. Data is collected and the following calculations made and consolidated for presentation to the decision-

maker:[3]

	Program A	Program B
Initial Investment Costs	$12,000,000	$16,000,000
Annual Operating and Support Costs	2,000,000	1,500,000
Present Value of Total Costs	41,656,000	53,500,000
Annual Benefits	3,000,000	2,500,000
Present Value of Benefits	44,484,000	62,500,000
Cost-Benefit Ratio	1.07	1.17

Faced with only this information, the decision-maker would conclude that Program B seemed the more attractive. Yet if the 4.5 percent rate of discount had also been used in Program B calculations, a cost-benefit ratio for that program of 0.97 would have resulted. This type of disparity increases as the gap widens between interest rates used in discounting costs and benefits of alternate programs.

Development of cost-benefit analysis. -- Evaluation by the government in general and the military in particular of the costs and benefits involved in programs under consideration has often been performed in an erratic manner. This was especially true prior to the introduction of program budgeting and PPBS planning (discussed in Chapter II), the purpose of which was to introduce more scientific budgeting and planning techniques into government. The initial

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[3]For more detail concerning this problem, see U.S., Controller General, Survey Of Use By Federal Agencies Of The Discounting Technique In Evaluating Future Programs, pp. 13-16.

thinking pertaining to a formal statement of cost-benefit analysis seems to have taken place in France during the nineteenth century.[4] The first attempt to actually apply the theory to public investments, however, took place in this country in the 1930's. A key influence was the Flood Control Act of 1936 which required that benefits, to whomever they might accrue, should be in excess of costs if a project were to be undertaken. The technique of cost-benefit analysis was soon being used to demonstrate that requirements of the law were being met.

It is, however, "...no accident that benefit-cost analysis had its origin and highest development in the field of water resources. That is the field in which government operations are most analogous to private business and in which the highest proportion of outputs -- water and power -- are salable commodities bearing relevant market prices."[5]

Over the years government cost-benefit procedures have gradually become more formalized. It is still true, however, that there is no one particular reference which details general methods

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[4]See Stephen A. Marglin, Public Investment Criteria (Cambridge, Mass.: The M. I. T. Press, 1968), p. 16 for more historical detail.

[5]Dorfman, ed., Measuring Benefits of Government Investment, p. 8.

by which cost and benefits are to be valued. Moreover, while in certain specific areas of government activity such as water resource management and public health activities the techniques of cost-benefit analysis have proven of significant value, little progress has been made in developing this tool so as to make it more useful in helping to direct development and allocation of the federal budget in accordance with planned national priorities.

Cost-benefit analysis has as its primary objective the providing of assistance to managers in attaining desired program objectives. Some types of proposed government expenditures, however, lend themselves more easily than do others to some sort of direct measurement of related costs and benefits.[6] In the case of proposed national defense programs measurement of costs and benefits may be rendered far more difficult due to unique conditions of uncertainty. In addition, political and social pressures may have an important impact on the decision process, yet their specific influences may not be readily quantifiable.

Cost-Benefit Analysis in the Department of Defense

Reference has been made above to the introduction (under the

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[6] For instance, see Ibid., for examples of how cost-benefit analysis is used in such areas as Research and Development, Outdoor Recreation, Civil Aviation and Urban Renewal.

leadership of Hitch and Enthoven) of more highly quantitative, analytical techniques into DOD beginning in the early 1960's. Alternatives for the accomplishment of planned objectives were often constructed as highly complex systems and hence the genesis of the term systems analysis.

Systems analysis in essence grew out of World War II operations analysis, but introduced more higher level judgment and intuition into the decision process. In accordance with these procedures it became accepted practice to attempt to arrive at decisions concerning major programs through making systematic analyses of program alternatives evaluated in terms of estimated military worth and expected costs. The objective of this procedure was to establish a more rational framework for decision-making.

As systems analysis techniques became more developed, they became a means of attempting to predict the future, of deciding on objectives based on this future expectation, and on the evaluation of alternatives for achieving these objectives. Military experience, as such, gradually began to be accorded a lesser role. The expected performance of human beings, for instance, was often ignored since it was difficult to define in analytical terms.

Two significant problems developed in the use of these techniques which are to some extent still in existence today. The first of these had to do with the treatment of uncertainty. Uncertainty in the

military setting can be classified into two main categories -- uncertainty of a technological, strategic, or political nature and statistical uncertainty deriving from random chance occurrences. The use of mathematical methods (such as simulation) to deal with the latter type of problem may only be expensive window dressing if the former type of uncertainty is potentially large yet not recognized.

A second problem area concerns the ability to realistically evaluate appropriate costs and benefits. This is perhaps the heart of the matter of efficient allocation of resources in a military setting. In general, military costs were not previously and are not now considered in an opportunistic sense. Military logisticians have been trained to think almost exclusively in terms of outlay cost. At the level of the ILS logistician, it may be that this is inevitable. A problem arises, however, when inadequate attention is also devoted to this matter at higher levels. But the real problem enters in trying to measure the benefits or military worth of one particular system. How should the ILS logistician calculate the benefits to be realized from support of this system? The answer would seem to be that precise measurement or at times even definition of all benefits may be virtually impossible.

In a normative economic sense, a benefit can be measured by consumer willingness to pay for a good or service. In the case of

national defense expenditures, however, it is often difficult to identify and value output as well as measure public willingness to purchase it. Speaking to this general problem area, Hitch and McKean state that

> ...the choice of an appropriate economic criterion is frequently the central problem in designing a systems analysis. In principal the criterion we want is simple enough: the optimal system is the one which yields the greatest excess of positive values (objectives) over negative values (resources used up, or costs). But as we have already seen, this clear cut solution is seldom a practical possibility in military problems. Objectives and costs usually have no common measure....[7]

It is also clear that political as well as economic considerations enter into the type and amount of national defense goods and services produced. Decisions concerning this production are inherently subject to value judgments and political pressures. Cost-benefit analysis as a precise mathematical technique is thus somewhat limited in its applicability to the study of national defense production due to the many immeasurables which may be encountered. This limited applicability does not, however, mean that the tool is of no use to the ILS logistician. The importance of cost-benefit type studies flows from the fact that by their nature they require some manner of comprehensive consideration of all possible relevant factors in a decision situation.

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[7]Hitch and McKean, The Economics of Defense in the Nuclear Age, p. 120.

The objective of the ILS logistician is not, of course, to attempt to maximize output or benefits based on the primary utilization of any one single element. Rather he should have as his objective the attainment of the stated support objective through the lowest collective cost of element inputs. Since benefits in many military situations are hard to identify and evaluate, however, a method that has been devised to circumvent the problem of benefit measurement is first to identify through some decision-making process, political or economic, the objective(s) or goal to be achieved.

Cost-effectiveness technique. -- Having established these objectives, a "cost-effectiveness" technique can then be used whereby alternate possibilities for future action are evaluated in terms of their effectiveness, or ability to achieve the stated objectives. Cost-effectiveness analysis in this sense has been characterized by one author as "The quantifiable examination of alternative prospective systems for the purpose of identifying the preferred system and its associated equipment, organization, etc. The examination aims at finding more precise answers to questions and not at justifying a conclusion."[8]

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[8] I. Heymont, Guide for Reviewers of Studies Containing Cost-Effectiveness Analysis (McLean, Virginia: Research Analysis Corporation, 1965), p. 57.

The end result of all military procurement decisions can be considered as the allocation of scarce economic resources among competing uses. Cost-effectiveness in this context may be therefore throught of as a measure of value received (effectiveness) for resources expended (cost). The Five-Year Defense Program referred to in Chapter II reflects an attempt to array missions and programs in an orderly fashion so that the resources required for the implementation of each can be listed and compared with the benefits expected as the result of attainment of mission objectives. The advantage of such a procedure lies in its ability to systematically compute and present data in a format designed to aid the decision-maker in arriving at his choice.

Cost-effectiveness analysis as here defined has, unfortunately, come to have the meaning to many people of a mathematical process which results in the achievement of economy first and effectiveness last.[9] This is not, however, the intended connotation. What is meant, rather, is that the analytic techniques discussed in this chapter should be considered as tools to aid in the decision-making process, but in no sense should they be considered a complete substitute for sound judgment. The purpose of cost-effectiveness studies is not

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[9] For a further discussion of this problem see Donald H. Heaton, "System/Cost Effectiveness in the System Engineering Process," Defense Industry Bulletin, July, 1969, pp. 34-37.

necessarily discovery of the cheapest system. In fact, these studies are (or should be) neutral as regards system unit cost. The objective should be to determine which system offers the greatest effectiveness in terms of attaining a program objective for a given outlay, or, alternatively, a particular level of effectiveness at least cost, depending on the decision criteria.

The most important task for the ILS logistician in this process might well be to help identify more clearly the objectives which the decision-maker is attempting to achieve. In so doing, he can put his professional expertise to best use in accordance with his own assessment of the feasibility of available alternatives. He will, of course, have to assume that the stated objective has been judged through the political process as one worth achieving. It is also important that he should not at this point confuse effectiveness in achieving the objective with system performance. Small increments in system performance can have profound influence on effectiveness. For example, the ability of a Polaris submarine (whose objective let us assume is to defend the West Coast) to remain submerged for say 10 percent longer may result in a vast increase in its effectiveness.

Thus the ILS logistician, having had the task presented to him of providing a particular level of support for a planned system, can then theoretically combine ILS elements so as to attain this ob-

jective in the most "cost-effective" manner. Such a course of action is, however, actually only a restatement in different form of the theoretical approach of economic optimization discussed in Chapter III. One problem which the logistician faces in implementing this procedure is that he does not at present have direct control over the elements he must use, but rather must deal through many administrative units. This at a minimum delays action and also greatly increases the possibility of parochial decisions at various points in the operational chain to the detriment of efficient resource allocation. Another and related problem is that logistics data has in the past generally been compiled in such a manner that it deals with individual ILS elements thus rendering it difficult to ascertain total system costs when elements are combined. These problems are beyond the scope of this paper. Nevertheless they will have to be resolved by DOD if the theoretical goal of economic efficiency is to even be approached.

The fact that judgment has been interjected into the cost-effectiveness procedure in a random manner has in the past resulted in cost and/or performance estimates for an individual system alternative being over or under-stated depending on whether that alternative was being advocated by the decision-makers. This point will be further illustrated below by means of an example dealing with Naval

nuclear propulsion. From an ILS standpoint, the obvious solution to such a problem would seem to lie in the systematic training and development of a highly motivated, professional corps of logisticians who would be expected to participate in the determination of system objectives and the selection of criteria on the basis of which alternatives would be rated. This participation is a necessary step in the achievement of economic efficiency because in general each military decision must be weighed on its own merits. There has as yet been no method devised by which it is possible to directly compare the true effectiveness of different military programs. For each individual program, however, the logistician may well be able to help establish the over-all goal or objective sought, and then evaluate the contribution which a particular combination of elements can make toward reaching that goal or objective within the over-all constraint of his support budget limitations.

A crucial point in this analysis is that appropriate measures of both cost and effectiveness be used and that ". . . <u>all</u> costs and predictable effects of the <u>relevant decision</u> be given their appropriate weight in the choice."[10] The logistician's role in this is potentially very important as can be seen from the statement of the Assistant

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[10] Armen A. Alchian, "Cost Effectiveness of Cost Effectiveness," in <u>Defense Management</u>, ed. by Enke, p. 75.

Secretary of Defense (Installations and Logistics) that "...in preparing our cost-effectiveness analyses, we must include in the 'cost side' of the equation the cost of supply, maintenance and down-time; and...we must include in the 'effectiveness side' of the equation the value of greater operational up-time and longer mean-times-between-failure."[11] The analysis should thus be so structured that a great deal of time and effort is not addressed to wrong or irrelevant questions.

Limitations and applications of cost-effectiveness analysis. -- It has been indicated above that cost-benefit analysis often cannot be directly applied in decision-making problems involving national defense program evaluations. Once objectives are agreed to, however, a more limited form of analysis -- cost-effectiveness -- can help, if properly applied, to clarify narrower issues. This process can be considered valuable if it only succeeds in forcing all concerned to think about the stated objectives, how they were arrived at, and what means are available for their realization. Certainly a major task of the logistician-analyst in such a situation is to help the final decision-maker become aware of the consequences of taking alternate courses of action. It must not, however, be forgotten that military decision-making operates in a highly bureaucratic environment. As one writer

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[11]Morris, address presented at the Electronics Industries Symposium, March 7, 1968.

has put it "...issues cannot be treated wholly in isolation. The quality of information is very much influenced (and biased) by the structure of and alliances within the bureaucracy. The methodology chosen for analysis will in itself introduce a specific form of bias."[12] It is important, therefore, for the logistician to be aware of the limitations as well as the possibilities of the cost-effectiveness analytical process. Probably one of the most damaging biases apparent in many DOD analyses is the honest, although often misguided, conviction on the part of the analyst of the rightness of his own views, a conviction which he then proceeds to justify by some quantitative means.

The logistics analyst should also be aware that the political process, substituting in the sphere of government for market determination, virtually forces an attempt at foot-in-the-door tactics by all concerned, leading advocates to overstate benefits and understate the cost of "their" choices. The reward system at present often favors those programs or ideas which are politically most acceptable, and not necessarily those which best utilize resources. The present budget authorization and appropriation process with its emphasis on current rather than total future costs also contributes to the problem. These are matters with which those in authority in government must

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[12] James R. Schlesinger, Systems Analysis and the Political Process (Santa Monica, Calif.: The RAND Corporation, June, 1967), p. 2.

come to grips if theoretical approaches are to have any chance of working.

The ILS logistician is, however, even now in position to conduct a form of cost-effectiveness analysis as he seeks to obtain the best combination of elements available to support a given system or objective. As one example of this, analysis recently performed by Navy and contractor personnel indicated that manpower requirements for a particular system could be reduced from thirty-one men to twenty-four if certain material modifications were made. Based on the number of systems projected to be deployed, it was estimated that a total savings of some 1400 man years would result. Using an average cost of $10,000 per man year, potential savings were thus calculated to be $14 million. Assuming that both the original and modified systems were of approximately equal effectiveness, the logistician would then be in position to weigh the benefits from manpower savings against the cost of the indicated modifications.

Thus it is apparent that it is the incremental costs and benefits of each alternative which assume importance. This type of calculation, of course, is not limited to the manpower element. Similar analysis can and should be carried out for all applicable ILS elements when a new or modified system is being considered. Results of these calculations can then be subjected to such tests as

sensitivity analysis to determine how results change as the independent variables are changed. The Vice Chief of Naval Material, in fact, has estimated that calculations of this general nature have the potential for reducing the life cycle support costs of major ship programs by $100 million to $200 million.[13]

In carrying out a cost-effectiveness analysis, the logistician should seek to quantify those factors which logically lend themselves to such analysis in order to present the results to the decision-maker in such a manner that judgment can then be used in combining qualitative factors with quantitative data. Cost-effectiveness analysis in itself, of course, expends resources and thus should not be conducted merely as an academic exercise, but rather with the objective of making a definite contribution to the decision-making process.[14]

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[13]This opinion was presented in a memorandum of March 17, 1969 from the Vice Chief of Naval Material to the Vice Chief of Naval Operations.

[14]It is interesting to note in this respect that Department of Defense Instruction 7041.3 provides a format for systematically identifying the costs and benefits of proposed DOD investments associated with alternative methods of achieving a particular objective so that the alternative can be identified whose total discounted cost is lowest. The proposed acquisition of new military systems falls within the scope of this instruction, including "...the costs of support services required on an annual basis...." Yet no apparent attempt is made to clearly require the inclusion of the specifically defined Integrated Logistic Support elements or to make it clear that Acquisition Managers and designated ILS logisticians should use the format in their calculations. In fact, no specific guidance is given to the logistician along these lines.

It should not, however, take the place of, or be used as a pretext for overriding expert judgment and supplanting it instead with the preconceived notions of the analyst. Clark cautions against such quantitative overemphasis when he states that "...what we find today is a curious mixture of dollar-money accounting, usually down to the last penny of 'costs' of weapon systems, these costs to be pitted against their 'worth' in the overall strategic pattern of the country, a worth the Department of Defense is not able to express in generally acceptable numbers."[15] Some benefits, however, even though they are intangible and immeasurable do need to be considered in some objective fashion. Priceless in this context thus should not necessarily be considered the same as worthless. All relevant factors should be taken into consideration, qualitative as well as quantitative.

Problems in the Use of Cost-Benefit Type Analysis -- A Case Example

A long and stormy controversy has taken place within the Defense Establishment itself and between DOD and the Congress over the issue of whether or not to provide for nuclear propulsion in new major surface warships for the Navy.[16] An investigation of some

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[15]Clark, The New Economics of National Defense, p. 204.

[16]U.S., Congress, Joint Committee on Atomic Energy, Naval Nuclear Propulsion Program--1967-68, Hearings, before the Joint Committee on Atomic Energy, Congress of the United States, 90th Cong., 1st and 2nd sess., March 16, 1967 and February 8, 1968

parts of this controversy is appropriate for this study because:

1. Much of controversy centers around the manner in which cost-effectiveness analysis was used in the decision-making process.
2. Many of the points which came into question involve logistics matters and hence are of direct concern to ILS.

The fiscal year 1963 DOD authorization bill included provision for the construction of a new aircraft carrier, designated CVA-67 and subsequently named the John F. Kennedy. At this time, only three Navy surface ships had been constructed which were designed for nuclear propulsion. These were the aircraft carrier Enterprise, included in the fiscal year 1958 shipbuilding program, the cruiser Long Beach in the 1957 program, and the frigate Bainbridge in 1959. In addition, a second frigate, the Truxtun, had been authorized in 1962. In the case of the Truxtun, Congress was responsible for changing one of the seven frigates requested by DOD that year from oil to nuclear power.

With the large scale adoption of systems analysis and cost-effectiveness studies by DOD in the 1960's, a growing feeling became evident among the civilian leadership that the advantages of nuclear power for surface ships were not worth their higher cost -- in

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contains unclassified versions of pertinent studies and correspondence. "Major" in this context is defined as displacement in excess of 8,000 tons.

particular higher initial cost. As evidence of this feeling, a third nuclear frigate, which had been authorized and funded by Congress in the 1963 program, was subsequently cancelled by the Secretary of Defense prior to initiation of construction.

In the light of this record, attention by all concerned became focused on plans for the CVA-67. The original Navy request was that this ship be nuclear-powered. Apparently as requested by DOD, however, the Navy changed its recommendation to a conventionally-powered aircraft carrier before the fiscal year 1963 budget was formally submitted. It should be instructive to the ILS logistician to critically evaluate the role played by cost-effectiveness analysis in this decision, particularly in view of the strong support voiced in Congress for the construction of a nuclear surface fleet.[17]

The Navy nuclear-powered submarine fleet, in contrast to the surface fleet, has been steadily growing since the 1950's. As of February 21, 1968, in fact, seventy-four nuclear-powered submarines were in operation. As regards nuclear surface ships, however, the Secretary of Defense stated in a letter to Chairman, Joint

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[17] For example, after executive hearings aboard the Enterprise in March and June of 1962, the Joint Committee on Atomic Energy stated: "The United States must prosecute vigorously the conversion of the Navy to nuclear power in the surface fleet as well as in the submarine fleet." The Joint Committee also urged, to no avail, that the DOD reconsider its position that CVA-67 should be conventionally powered.

Committee on Atomic Energy that:

> . . . on a ship-for-ship basis, nuclear power offers definite advantages. But nuclear power adds a great deal to the cost of ships. So, no matter how much we spend on naval forces, we face the choice between a given number of nuclear ships and the larger number of conventional ships that we could buy and operate for the same total cost. In the case of submarines, the added effectiveness for nuclear power is so great as to far outweigh the costs. [18]

Although by that time advances in technology had made the building of nuclear aircraft carriers more attractive from a cost standpoint, the clear implication was that nuclear submarines had demonstrated themselves to be "cost-effective" whereas, at least by 1963, nuclear surface ships had not.

Called before the Joint Committee on Atomic Energy to explain this position, the Secretary of Defense stated -- without detailing exactly why -- that he considered the advantages of nuclear propulsion to be worth only about $25 million to $50 million over the ship's life cycle -- about .05 percent of the estimated cost of the ship and aircraft squadrons. [19]

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[18] Letter, Robert S. McNamara to Hon. John O. Pastore, May 1, 1967.

[19] See Clark, The New Economics of National Defense, pp. 67-70 for one author's view of this controversy. It is difficult to evaluate the significance of the stated percentage figure. More relevant would have been a comparison of the added benefit with the added cost over the ship's life cycle.

In support of this position, the following information was presented to the Committee:

Proposed nuclear carrier initial investment	$371.0 million
Initial nuclear cores	32.0
Additional aircraft squadron	37.4
Total	440.4
Conventional carrier initial investment	277.2
Difference	$163.2 million

Referring later to this presentation the Assistant Secretary of Defense for Systems Analysis wrote "... CVA-67 will cost about 280 million dollars. Had it been decided to make her nuclear-powered, she would have cost over 400 million dollars. For roughly 400 million dollars one can buy either a nuclear-powered carrier or a conventionally-powered carrier plus four 3,500 ton escorts."[20]

It seems evident from this exchange that the only approach taken by DOD analysts was one of attempting to maximize the effectiveness of a pre-selected system within the constraints of a fixed over-all budget. There was little, if any, attempt made to first determine which particular system might offer the greatest military effectiveness, this step to be followed by an evaluation of the effect on total outlay required, support and logistic factors included. Commenting on DOD's analysis, one U.S. Congressman subsequently stated that the Joint Committee on Atomic Energy had been told that

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[20] Enthoven, "Systems Analysis and the Navy," p. 102.

"...the choice we face is between a given number of conventional ships and a smaller number of nuclear ships at the same cost. In other words, to improve a weapons system, we must reduce the number of weapons to pay for it."[21] He then went on to emphasize that he did not share this view.

There seem, therefore, to have been two major sub-problems involved in this controversy, both of significance to the logistician. The first involved the determination and specification of the objective which cost-effectiveness analysis should be attempting to help achieve. The second problem had to do with determination of the specific elements of cost and benefits which were to be evaluated by DOD analysts, and what, if any, effect the method in which this was handled may have had on the results obtained. The solution to the second problem depends on resolving the first. As has previously been noted, cost-effectiveness analysis should theoretically be neutral as regards the unit cost of any particular system. A writer who has been instrumental in development of the new analytical approach in DOD has noted in this regard that "The systems analyst... can tell the decision-maker how many more targets would be destroyed if 200 new bombers were added to the planned force and how much

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[21]Congressman Chet Holifield, remarks at the launching of U.S.S. Truxtun, DLGN-35, New York Shipbuilding Corp., Camden, N.J., Dec. 19, 1964.

they would cost; he can rarely demonstrate whether they should or should not be added."[22] Yet this may well be exactly what the DOD studies attempted to do in the case of the Navy aircraft carrier.

In support of the position that CVA-67 should have been nuclear-powered, a number of advantages which would accrue from this type of propulsion and which would add significantly to the ship's military effectiveness were claimed by the Navy. These included:

1. The capability to steam at high sustained speed for almost limitless periods of time. This, in turn, would afford:
   a. Increased tactical flexibility and freedom of independent action.
   b. Capability to transit at high speeds to take advantage of logistic support available in less vulnerable locations.
   c. Capability to carry out assigned missions over a greater perimeter.
2. Reduced ship vulnerability because of:
   a. Reduced necessity to receive logistics support in direct combat areas.
   b. Improved capability for sealing the ship due to elimination of air intakes required by conventionally-powered ships.

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[22] Charles J. Hitch, Decision-Making for Defense (Berkeley, Calif.: The University of California Press, 1965), p. 76.

3. Greatly reduced freedom from logistics support, which means:
   a. A lower requirement for mobile support forces;
   b. A lower requirement for advanced support bases.
4. Greater military effectiveness, due to:
   a. Ability to remain on station for a longer period of time.
   b. Increased ability to take advantage of weather conditions.
5. Increased capability to generate ships service electrical power to service advanced electronic equipment.

Whether or not these stated advantages were adequately evaluated in cost-effectiveness studies carried out by DOD is not clear. It can be instructive for the logistician to consider some of the more controversial aspects of reports such as the Naval Warfare Analysis Study conducted for DOD by the Center for Naval Analysis (CNA) so that similar problems may be recognized and handled in his own analytical work. First among these considerations is the fact that the objective of the analysis was, in fact, never clearly defined. It was apparently assumed by DOD that the objective should be to maximize the cost-effectiveness of a given type of system (in this case, an aircraft carrier) within the basic constraint of a limited, one-year ship construction budget.[23] The Navy, and certainly the

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[23]In support of this, the Secretary of Defense, in a letter of December 1, 1965 to the Chairman, House of Representatives Armed Services Committee, wrote: "I think that it is absolutely essential that we buy the maximum of defense for any given dollar of expenditure."

Congress, however, assumed that maximum military effectiveness should be the prime objective, provided, of course, that the cost of the more effective alternative should not be significantly greater than its competitors.[24] In this regard, a Joint Committee on Atomic Energy report on this subject stressed that "The total lifetime cost of the nuclear carrier with its aircraft is estimated to be only about 3 percent more than the lifetime cost of the conventional carrier with its aircraft. . . the increased cost of nuclear power is not significant in relation to its demonstrated advantages."[25] In view of this controversy, it can be seen that it is essential in any output maximization or resource minimization problem that the logistician clearly understand the objective which is to be attained as well as criteria for judging success in attainment.

A second problem area concerns the fact that disagreement took place over which relevant considerations were quantified and which were not. Consider first certain items that were not quantified,

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[24]As an example of this thinking, the Congressional Hearings referred to in footnote 16 point out on p. 8 that "In Southeast Asia today the United States is once again faced with the bitter reality that what counts in war is 'military effectiveness' -- not 'cost-effectiveness'." See also Ibid., p. 76 for the full statement of Admiral Rickover which sets forth the belief that "Nuclear propulsion should be judged on its own merits. For ship types where the increased military effectiveness is worth the higher cost we should spend the dollars necessary. . . . "

[25]Ibid., p. 264.

yet might have been. The Chief of Naval Operations, in his endorsement to the interim report of the CNA study referred to above, reflected on this matter when he stated:

> Those aspects of tactical superiority that come strongly into effect in wartime and yet are difficult to quantify analytically are not in this study. I have in mind the military value of greater freedom to move far and fast on demand; in other words, the new order of capability to meet swiftly changing circumstances that nuclear power provides and that conventional power cannot match. We could make a more realistic comparison of nuclear and conventional carriers if we could find a way to embrace a full appreciation of these most important assets.

Yet many of these "difficult to quantify analytically" items probably could have been measured. Of particular interest to the logistician in this regard is the fact that the most serious limitations of DOD studies in this area have to do with the failure to treat realistically and in a quantified way the advantage of relative freedom from the necessity for external logistics support. Specifically, DOD cost-effectiveness comparisons were generally based on the somewhat inappropriate assumptions that:

1. Tankers and oilers needed to supply fuel for oil-fired warships would always be available and would be able to operate unhampered by the enemy.
2. The fuel oil needed to run conventional ships would always be readily available whenever and wherever needed.

As a result of these assumptions, related cost factors for potential losses were not fully developed.[26] If the full impact of such costs had been included in the cost-effectiveness calculations, the final result would certainly have been more favorable for nuclear propulsion.

Certain other items, however, were quantified and used in the calculations, but seemingly in a somewhat questionable manner. In the figures presented to Congress by DOD, for example, it can be seen that the costs involved in procurement of an additional squadron of aircraft were charged against the nuclear carrier simply because the ship, due to its configuration, would be able to accommodate them. Yet all it would have taken to avoid the incurrence of this cost would have been a subsequent decision not to procure the aircraft. In addition to this questionable calculation, the cost of the nuclear reactor cores, which would have been able to power the ship for at least seven years, were charged against the nuclear ship alternative whereas no charge was made against the conventional alternative for the cost of fuel oil to provide for a similar period of operation. This action apparently was taken because conventional fuel could be pur-

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[26]This despite the statement of CNO that "... the vulnerability of our overseas logistic supply lines is greater today than at any time in the past and is continuing to increase...." See Ibid., p. 72.

chased gradually out of operating rather than construction funds. The concept of life cycle costing was thus slighted in this case in favor of the exigencies of current year ship construction budget limitations.

In view of the above, it is difficult to avoid the conclusion that the purpose of DOD cost-effectiveness analysis in this case was to develop figures to be used to support a pre-formed subjective opinion. One writer notes in this regard that as a result of having researched all pertinent testimony of the Secretary of Defense pertaining to this decision, he concludes that "In his very lengthy testimony, Mr. McNamara came back again and again to the difference in money costs but, though several Senators pressed him with intelligent and pertinent questions, he never explained why the advantages of the nuclear carrier were not worth the difference in these costs."[27]

Applicability of Cost-Benefit Type Analysis to ILS -- Conclusions

Cost-benefit type analysis can provide specific guidance to decision-makers where objectives have been definitively stated, criteria for judging alternatives are clear, and both benefits and costs are quantifiable in a fairly non-controversial sense. In the

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[27]Klaus Knorr, "On The Cost-Effectiveness Approach To Military R & D: A Critique," paper presented for the 29th national meeting of the Operations Research Society of America in Santa Monica, Calif., May, 1966.

case of public goods such as national defense, however, costs in an opportunistic sense as well as a realistic approximation of benefits are virtually impossible to assess. Yet even in situations such as this, analysis can be beneficial by seeking to quantify those factors which lend themselves to such manipulation and pointing out for consideration of the decision-maker those which do not. When analysis is conducted, it is perhaps inevitable that judgment should enter. It should therefore be realized that perhaps as much art as science is involved in use of this technique. The practitioner must avoid leaving the impression that he can provide a "proof" for nearly anything, a charge which has been leveled against DOD analysts.[28]

The objective of cost-benefit type analysis should be to help to minimize the collective costs of inputs in the achievement of some specified goal, or, alternatively, to maximize the output attainable within a limited budget. The precise goal or objective, however, needs first to be clearly defined. In addition, cost analysts need to have available the benefit of expert engineering knowledge so that the costs of acquisition, construction, maintenance and so on can be more accurately estimated. The contribution of the experienced military

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[28]For example, see excerpts from the testimony by Admiral Rickover before the Joint Committee on Atomic Energy on July 25, 1968 as reported in The New York Times, Sept. 20, 1968, Section C, p. 28.

logistician, however, can also be vitally important. He alone can provide much of the experience and knowledge that is needed to place a realistic subjective evaluation on variables which defy precise measurement. The logistician is thus in an unique position to add to the effectiveness of analytical studies. But it is important that he also understand the limitations of such techniques. As one writer has put it: "As long as too much is not expected of cost-benefit analysis, it can make, and is making, significant contributions toward governmental decision making."[29]

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[29]Due, Government Finance: Economics of the Public Sector, p. 69.

VII

AN INTEGRATING CASE EXAMPLE

> ...the essential logistics requirement for the future will be the attainment of greater management control and improved planning. [1]

The purpose of this study has been (1) to investigate the background for and development of the concept of Integrated Logistic Support Planning in the Department of Defense, and (2) to indicate how the ILS logistician might utilize certain of the newer tools of economic analysis and management science to make better decisions. These tools include indifference curve analysis, Bayesian statistical analysis, business logistics theory (particularly as it applies to the problem of inventory holding costs), and cost-effectiveness analysis. This chapter will now show how these concepts can be brought together in a typical ILS equipment procurement situation. The example presented below makes use of actual cost and performance data as the basis for development of a hypothetical yet realistic case. While the focus is on the procurement of one particular piece of

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[1] Geisler, The Impact of Changing Defense on Logistics Requirements, p. 8.

electronic equipment, the principles involved should also be applicable to many other procurement situations.

Case Assumptions

The logistician in this case is assumed to be faced with a decision to award a multi-million dollar contract for the procurement of a type of airborne radio widely used by the military services in a number of system applications. Certain basic data relating to an existing radio of the type in question have previously been presented in the latter part of Chapter III and in Table III-2 (Level 1). In summary, these data indicated that based on a purchase quantity of 800 units the radio would originally have cost $4,400 per unit if manufactured to a design reliability level of 150 MTBF hours. The analysis which follows assumes a request for quotes based on government contract specifications which call for (1) the reliability level of this basic type of radio to be increased for a new system use, (2) a planned life cycle of ten years, and (3) 1,000 of the new radios to be purchased both for originally installed equipment and as component parts to be held as support inventory. It is further assumed that the request for quotes provides for the contractual right of the government to receive supporting cost-reliability data from the competing bidders.

The logistician's "budget," as defined below, is stated to be $15 million. The contract is to be awarded to the lowest bidder

demonstrating at least a 93 percent probability of being able to produce radios at a reliability level to be subsequently negotiated. The management procedures which follow are to be used as helping to evaluate differences in the trade-off relationship between reliability level and total radio life cycle cost presented in competing bids. Basic concepts and methods discussed in previous chapters will be referred to as appropriate and made use of in this example.

In recent years defense contracts have generally stressed the need for higher levels of equipment reliability in order to maintain effectiveness standards in ever more sophisticated systems. Recall that the basic components of inherent availability as earlier defined in this study are reliability and maintainability. It is apparent that as reliability requirements in terms of MTBF hours are raised, procurement (acquisition) costs per unit will increase. As reliability is increased, however, maintenance (ownership) costs per unit may well decrease, at least up to some point. It should thus theoretically be possible to actually lower total life cycle costs up to this point by spending additional sums to extend equipment reliability. The logistician, faced with a budget constraint, should be interested in reviewing the bidders' proposals as an initial step in helping to determine the optimum attainable level of reliability.

It should be mentioned at this point that the "budget" referred

to in this case is considered to be that total dollar amount required to acquire and support the equipment over its designated life cycle. The logistician will normally not have budgetary control over all elements of cost in the life cycle. For the most efficient allocation of resources to be achieved, however, he should base his actions on all (discounted) costs that will be involved in the procurement regardless of (1) the timing of cost incurrence, (2) the funding appropriation, or (3) the finally affected administrative budget. It is a recommendation of this study that fiscal procedures be modified in the future as necessary to permit the ILS logistician to act in this fashion. The example below, in fact, assumes prior implementation of such a policy.

This case may essentially be considered a form of cost-effectiveness analysis within the scope of which economic theory, Bayesian statistical decision theory and inventory management considerations are brought to bear.

Basic Consideration from Economic Theory

In any procurement there are two main classes of data with which the logistician should be concerned. These relate to the factors involved in acquisition and ownership. Ownership, in turn, is composed of a number of different elements. In this study, these ownership elements are considered to be those ten which officially comprise ILS (see Appendix E). The logistician must be interested in seeing

how the contractor proposes to combine these elements to produce stated levels of reliability. The contractor's data, therefore, may be evaluated to this end in the manner indicated in Chapter III. Thus, if only two elements or inputs were involved the optimum position in

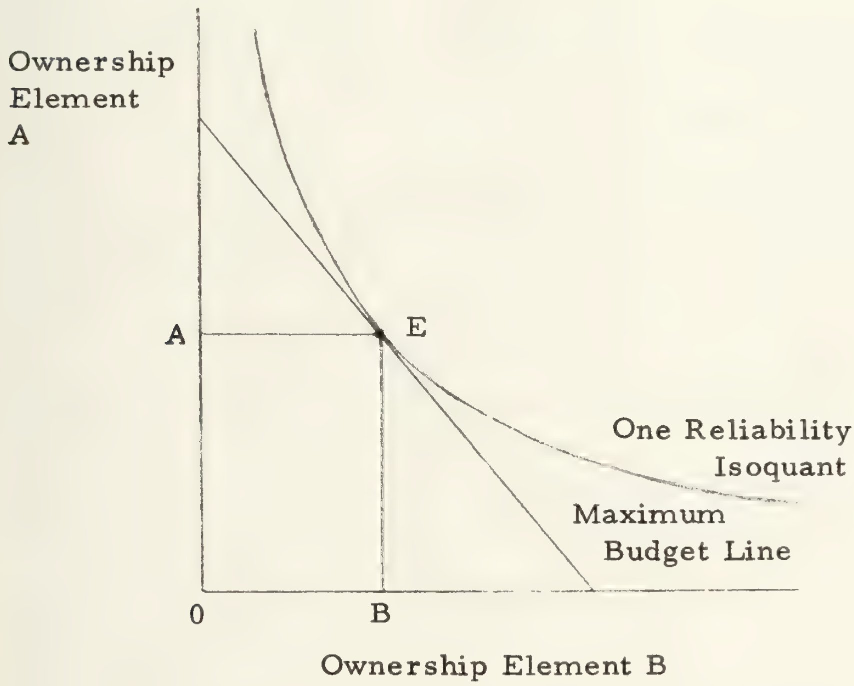

Fig. VII-1 -- Indication of an optimum position considering only two ownership elements as inputs.

terms of reliability output would be at point E as graphically indicated in Figure VII-1 with OB of ownership element B used as one input and OA of element A the other.

From the logistician's standpoint, however, acquisition as well as ownership costs must be considered in order that total life cycle costs may be properly evaluated. With this objective in mind,

and maintaining the same form of graphical presentation, the two valuable inputs could be considered as (1) feasible combinations of ownership elements, and (2) acquisition units. Thus there could be considered to be a reliability output trade-off relationship existing between additional units of a particular equipment and the elements of ownership involved with the equipment. Since each of these component elements is capable of being individually costed, the budget line concept can once again be introduced and a position of tangency sought as indicated in Figure VII-2.

Output is here defined in terms of reliability which, in turn, is dictated by system effectiveness requirements. As before, the exact location of the optimum position E will depend on whether the

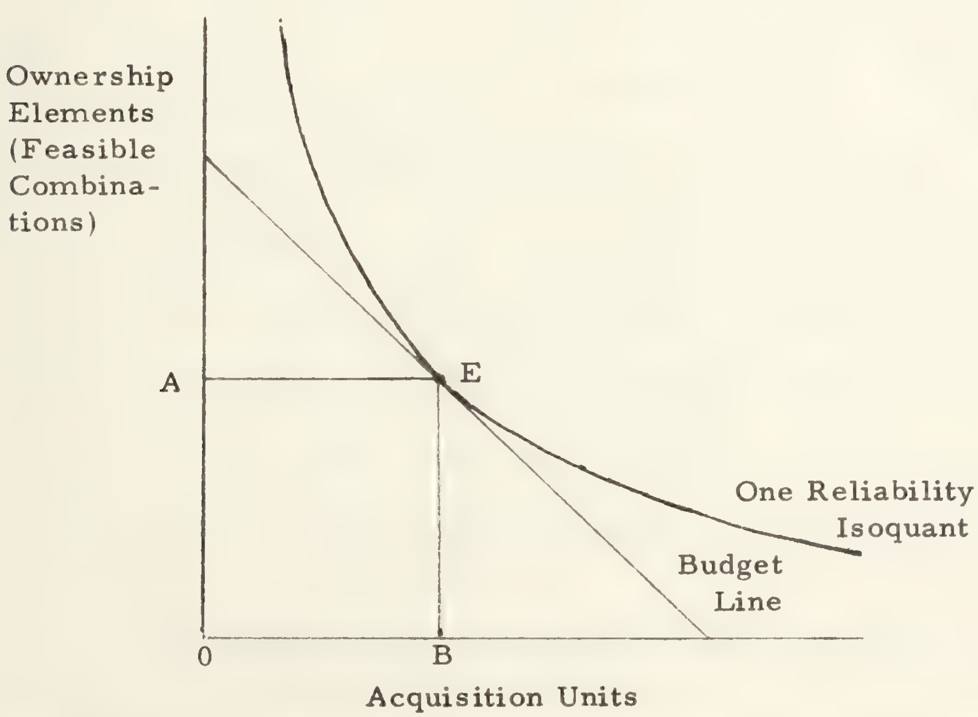

Fig. VII-2 -- Indication of an optimum position considering all life cycle elements.

budget line or some reliability isoquant is limiting. That is, it may be possible to reach a pre-designated satisfactory level of reliability, as determined by design engineers, without expending the full budget and this then becomes the objective. Alternatively, however, the objective may be to reach the highest level of reliability obtainable from the full budget available. Figure VII-2 demonstrates the latter case.

It should now be possible, however, to present these important basic theoretical considerations in an analytical framework which would be more directly useful to the logistician in this case. This could be done by using the cost data developed for the input quantities shown in Figure VII-2 and rearranging them as shown in Figure VII-3.[2] Reliability output would now be arrayed along the graph's abscissa. Figure VII-3 thus clearly shows the trade-off relationship between ownership and acquisition as it affects total life cycle costs while equipment reliability is being extended.

In Figure VII-3, the ten year life cycle cost curve reaches its minimum at a point which corresponds to a reliability of OB MTBF hours and total life cycle costs of OA. Assuming that the elements of ownership are being efficiently combined, then the optimum position is again at point E. If the system design called for a

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[2]It is assumed that all costs used in the example in this chapter are discounted to present value.

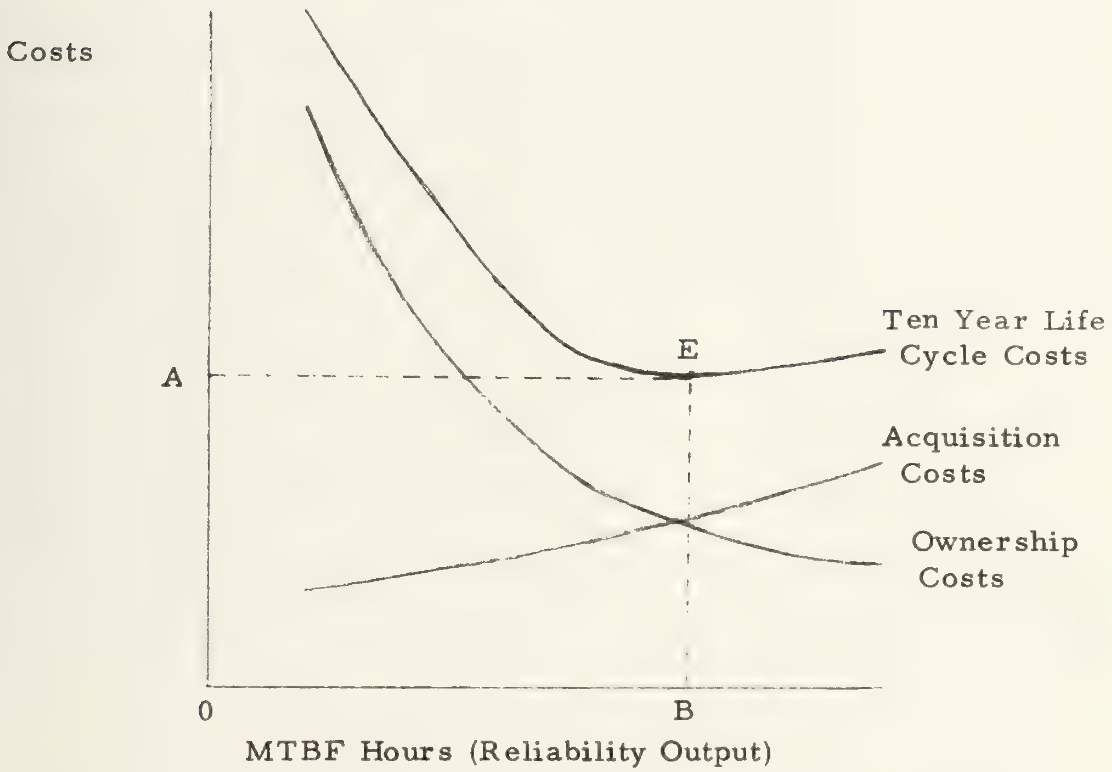

Fig. VII-3 -- Revised framework for determining an optimum position.

level of reliability higher than OB, the logistician could still purchase it subject to budget limitations, but he would have full knowledge that he is on the rising portion of the total cost curve. It should be stated here that an accurate estimate of the cost of all ownership elements may be unobtainable from the contractor. Thus the logistician must of necessity critically examine all aspects of the contractor's bid so that any needed corrections can be made prior to plotting such a graph.

The Use of Cost-Effectiveness Analysis

In evaluating the input elements as indicated above, it may be noted that certain benefits can result from increased reliability and mission effectiveness which are important, yet difficult if not impossible to quantify. Such benefits might include the potential saving of human lives and the resulting over-all contribution to national welfare. These benefits should be noted and presented to the decision-maker. Their essentially non-quantifiable nature, however, limits the opportunity for a complete cost-benefit analysis. Instead, the logistician could undertake the more limited form of cost-effectiveness analysis of each bid as defined in Chapter VI, comparing the respective quantifiable cost of obtaining various levels of MTBF reliability, within the relevant range.[3] Where differences appear the logistician should be interested in determining why they occur by specific ILS cost element. An example of a format that might be used for collection summary data by contractor-bidder for such analysis is shown in Table VII-1 below. This basic format could be revised from case to case as the

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[3]In carrying out his analysis, the logistician should, of course, seek to avoid the problem areas which have been experienced in such studies in the past. See Chapter VI, supra, for a more detailed discussion of this. As used in this chapter, the term relevant range refers to that span of reliability output associated with total life cycle costs $\leq$ the logistician's maximum budget.

situation might require and should be backed up by appropriate supporting detail.

TABLE VII-1

COST-EFFECTIVENESS ANALYSIS

EQUIPMENT A

CONTRACTOR Z

ILS Cost Element	Reliability Levels in MTBF Hours I	II	III	IV
Acquisition Costs				
Ownership Costs				
Maintenance (inc. Maintenance Planning)				
Support and Test Equip.				
Supply Support				
Transp. and Handling				
Technical Data				
Facilities				
Funding				
Management Data				
Totals				

The summary data for each contractor-bidder could then be transposed from individual analysis sheets and plotted on a single graph for easier comparison.

In order for such an analysis to be meaningful, each element of cost would have to be estimated as closely as possible. The contractor's estimation procedures should, therefore, be thoroughly reviewed by the logistician and his staff. As an example of the kind of approach that the logistician might expect a contractor to use in making his cost estimates, consider the procedure followed by a company which manufactures a type of equipment related to that being considered in this case. In order to collect all relevant data, this company sent engineers to six operational sites where maintenance information for this type of component was obtained as follows:

1. Equipment -- type, quantity, cost and usage rates.
2. Technical maintenance -- number and grade of technical personnel assigned; their training, pay and utilization; type and rate of spare parts usage; technical data requirements.
3. Clerical help -- number, grade, training, pay and utilization.
4. Test equipment -- type, quantity, cost and manner of usage.
5. Publications -- types and manner of usage.
6. Buildings -- type of construction, size, cost, location and usage.
7. Vehicles -- type, cost and method of usage.

The information that was obtained as a result of these activities is shown in Table VII-2. The equipment in question was priced at approximately $6,000 per unit. Among the pertinent points brought out by Table VII-2 are:

1. That ten year maintenance costs per unit are in excess of $98,000 or about 16.3 times the initial purchase price.
2. Technical services and repair parts taken together account for nearly 90 percent of total maintenance costs.

TABLE VII-2

AVERAGE MAINTENANCE COSTS PER YEAR[4]

EQUIPMENT B

Cost Element	Description	Cost	Percent
Tech. Services	Pay, training, site overhead	$6,710	68.4
Repair Parts	Cost, transportation, processing	2,080	21.2
Test Equipment	Maintenance, depreciation	430	4.4
Facilities	Upkeep, depreciation	340	3.5
Paper Work	Clerical	200	2.0
Miscellaneous	Publication costs, equipment and transportation	55	0.5
	Totals	$9,815	100.0

[4]The costs shown in Table VII-2 are average and non-discounted. In analyses performed by the logistician it would be preferable to show all costs discounted to present value indicating the importance of year of occurrence.

Having collected the basic data to support the figures listed in this table, it would be relatively easy for the contractor to perform the reconstruction necessary to use the ILS format suggested in Table VII-1. It is apparent that because of the higher percentage of total cost which results from these elements that the logistician will want to be particularly careful when reviewing the contractor's estimates dealing with technical services and repair parts (including inventory control).

Customer Service Level and Inventory Holding Cost Considerations

As a result of having obtained the summary and back-up data required to prepare Table VII-1, the logistician will be in position to have constructed, for each contractor-bidder, curves of the type shown in Figure VII-3.[5] This will merely indicate, however, the optimum level of reliability in terms of total life cycle costs. It will provide no information as to just how this optimum level relates to design requirements of the equipment in question. Hence the importance of the concept of customer service level and the reason for the stress placed earlier in this study on the necessity for the logistician to participate in design criteria decisions from the very beginning.

[5] Engineering interpolations between discrete reliability estimate points will, of course, be necessary. As will subsequently be seen, this can form the basis for later negotiation between the government and the contractor as to the reliability level finally decided on.

Assume, for instance, that the logistician is faced with a situation in which the desired level of reliability is positioned to the right of OB in Figure VII-3. This means that for each increase in MTBF hours beyond OB, a higher level of total life cycle costs would result. Perhaps the cost involved might exceed the budget allocated for this component. If so, then having been a part of the original design decision the logistician would at least have some idea as to whether he might ask the designers to consider relaxing the reliability requirements, or, alternately, to consider whether it might be possible to obtain additional funds. According to ILS implementing instructions the logistician is expected to take part in design decisions. In fact, however, he rarely does to any significant degree. It is, therefore, a strong recommendation of this study that procedures be devised by the Chief of Naval Material together with the operating Systems Commands to insure that this step is taken.

The business logistic concept of customer service level can thus be seen as being very important in an analogous sense to the military logistician. This is true as concerns design matters as referred to above, but also with reference to inventory items held as back-up. In Chapter V it has been noted how understatement of the costs of holding military inventory can result in misallocation of resources. Consider now the specific costs shown for Equipment B in

Table VII-2. It is a definite possibility that inventory holding costs may be understated, particularly if the practices followed at military operational sites are used as a basis for making calculations. To the extent that the logistician's investigation of the bidders' proposals finds that this situation exists, then these costs must be recalculated and ownership and total life cycle costs adjusted accordingly. As pointed out in Chapter V, the logistician should not simply accept rules of thumb in current use by military inventory managers which tend to understate the true costs of holding material. A more realistic valuing of this element may, of course, result in raising the total cost curve or even changing its shape as inventory holding cost charges affect one section of the curve relatively more than others. Yet such calculations cannot be avoided if the true life cycle cost involved in obtaining a particular level of reliability is to be shown.

The logistician, therefore, must investigate closely the contractor estimates involving inventory holding costs. If they are inadequate, he must increase them. If they are omitted, he may require a re-submission of the proposal. In general, however, the 15 percent figure widely used by inventory managers will probably not be sufficient. Particular attention should be given to an evaluation of the contractor's assumptions in calculating the holding cost components of interest, depreciation, and obsolescence (as discussed in Chapter V).

Bayesian Analysis and the Procurement Decision

Assume now that the ILS logistician following the general procedure and bearing in mind the considerations referred to above has requested and received proposals from three qualified bidders. He must now make a decision involving the letting of a contract for procurement of 1,000 airborne radios. Bid quotes are to show the costs of producing these radios with design reliability of 150, 240, 560 and 1200 MTBF hours respectively. Upon receipt of the proposals, the logistician begins with an analysis of Company C. Based on cost-reliability data submitted with the proposals, the cost-effectiveness form is completed as previously described. This is illustrated in Table VII-3. [6]

From the data presented in Table VII-3 it can be noted that as higher levels of reliability are built into the radio, acquisition

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[6] The acquisition and total ownership cost figures shown in Table VII-3 are actual for the indicated levels of reliability. The breakdown by ILS cost element is hypothetical, but generally based on the percentage distribution of costs estimated by the same company for related equipment in Table VII-2. It can be seen from Table VII-3 data that each element of cost will tend to follow its own trend as reliability levels are increased. For example, as MTBF hours are doubled technical costs should not be expected to be halved since the more highly sophisticated equipment will require increased engineering competence. Also, as reliability is increased, fewer personnel may be needed, however, specialized technical personnel will not be able to be reduced beyond some minimum number and thus may be less effectively utilized. The logistician should look for these kinds of trends.

TABLE VII-3

COST-EFFECTIVENESS ANALYSIS

1000 AIRBORNE RADIOS

COMPANY C

(Dollars in Millions)

ILS Cost Element	Reliability Levels in MTBF Hours 150	240	560	1200
Acquisition Costs	$ 5.0	5.75	7.5	12.5
Ownership Costs (ten year)	25.0	15.0	6.2	3.1
Maintenance	12.8	6.6	1.9	.4
Support and Test Equip.	1.1	.7	.2	.1
Supply Support	5.3	2.2	.6	.1
Transp. and Handling	.8	.7	.3	.2
Technical Data	.5	.7	.8	.9
Facilities	1.2	1.1	.4	.2
Personnel and Training	1.1	1.2	1.2	.9
Funding	.7	.5	.3	.1
Management Data	1.5	1.3	.5	.2
Totals	$30.0	20.75	13.7	15.6

costs will rise and ownership costs will fall.[7] Putting this basic data

[7] It is, of course, possibly true that beyond some point the quest for increased reliability will require such a technical effort that technical service costs could force the entire ownership cost curve into a rising trend. Such is not the experience, however, within the reliability range indicated in this case.

into the format of Figure VII-3, the following graph is obtained with the four discrete MTBF positions indicated, connected by a curve representing engineering interpolation.

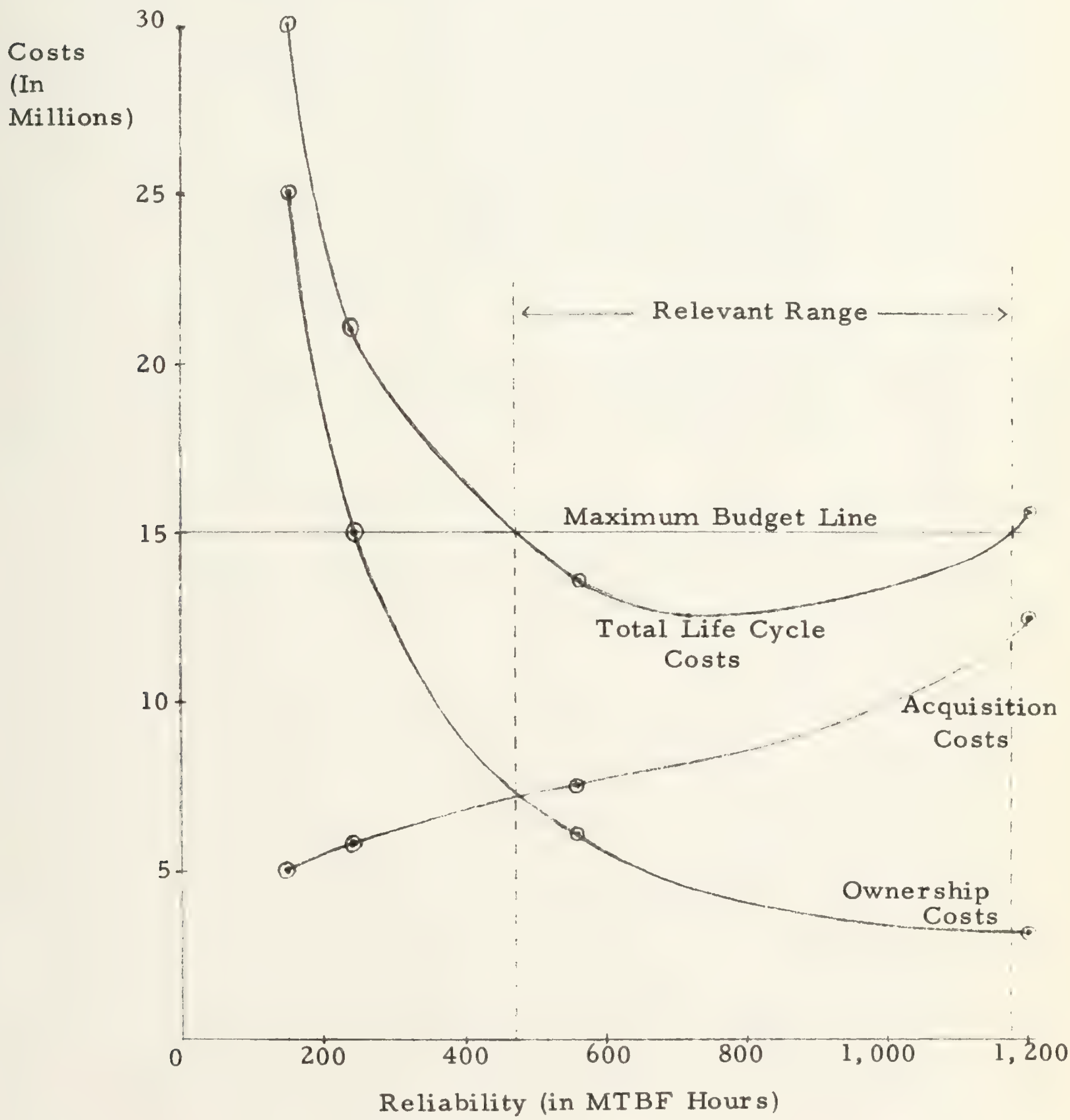

Fig. VII-4 -- Relationship between life cycle costs and MTBF hours for one type of airborne radio manufactured by Company C.

From this graph, the logistician can estimate that Company C should be able to supply radios of about 740 MTBF hours at lowest total life cycle cost even though no specific experimental model was tested in this range. This graph also demonstrates that it may often be possible to achieve cost savings while at the same time improving equipment reliability. In his evaluation of the cost-reliability trade-off presented above, the logistician must be careful to review the basis for costing of all ILS elements listed in Table VII-3. In particular, he should pay attention to those items involving inventory carrying costs. Assume for the moment that Company C finally won the award and that 1,000 radios were purchased at $9,000, 100 of them being designated for inventory. Assume further that the 100 radios (as component parts) were sent into inventory immediately and were used up or became valueless at the end of the ten year life cycle, the decline taking place on a straight line basis. There would thus be an average value equivalent to fifty radios in inventory each year during the life cycle. This would mean a total inventory value over the cycle of $9000 x 50 x 10 = $4,500,000. At 25 percent per year, total inventory carrying costs over the ten year life cycle would be 250 percent of this or $11,250,000. At 15 percent per year, however, total inventory carrying costs would be 150 percent, or $6,750,000, a difference of $4,500,000. There is no evidence that this large potential difference

in calculated total life cycle costs was considered in subsequent contract awards. Under the procedure recommended in this study, however, it would have been.

The decision process. -- Having evaluated the bid of Company C, the logistician would then proceed to follow the same sort of analysis with the two remaining bids. Having derived three total cost curves as accurately as possible, these curves could then be transferred to a separate form for comparison as indicated in Figure VII-5.

Now the logistician in this case is interested in obtaining as high a level of reliability as possible subject to cost considerations and dependent on the designated customer service level. Figure VII-5 helps the logistician to visualize which contractor, based on initial proposal data, appears to offer the most advantageous contractual arrangement.[8] It can be seen now that Company A offers the lowest total cost of all three bidders at a reliability level of about 500 MTBF hours. Having been a part of the initial system design decision process, however, the logistician knows that the preferred customer service level is 800 MTBF hours but that the 740 MTBF hour optimum position of Company C would be acceptable. The logistician also notes

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[8] It should be stated that the curve for Company C is based on actual data while those for Companies A and B are hypothetical for comparison purposes.

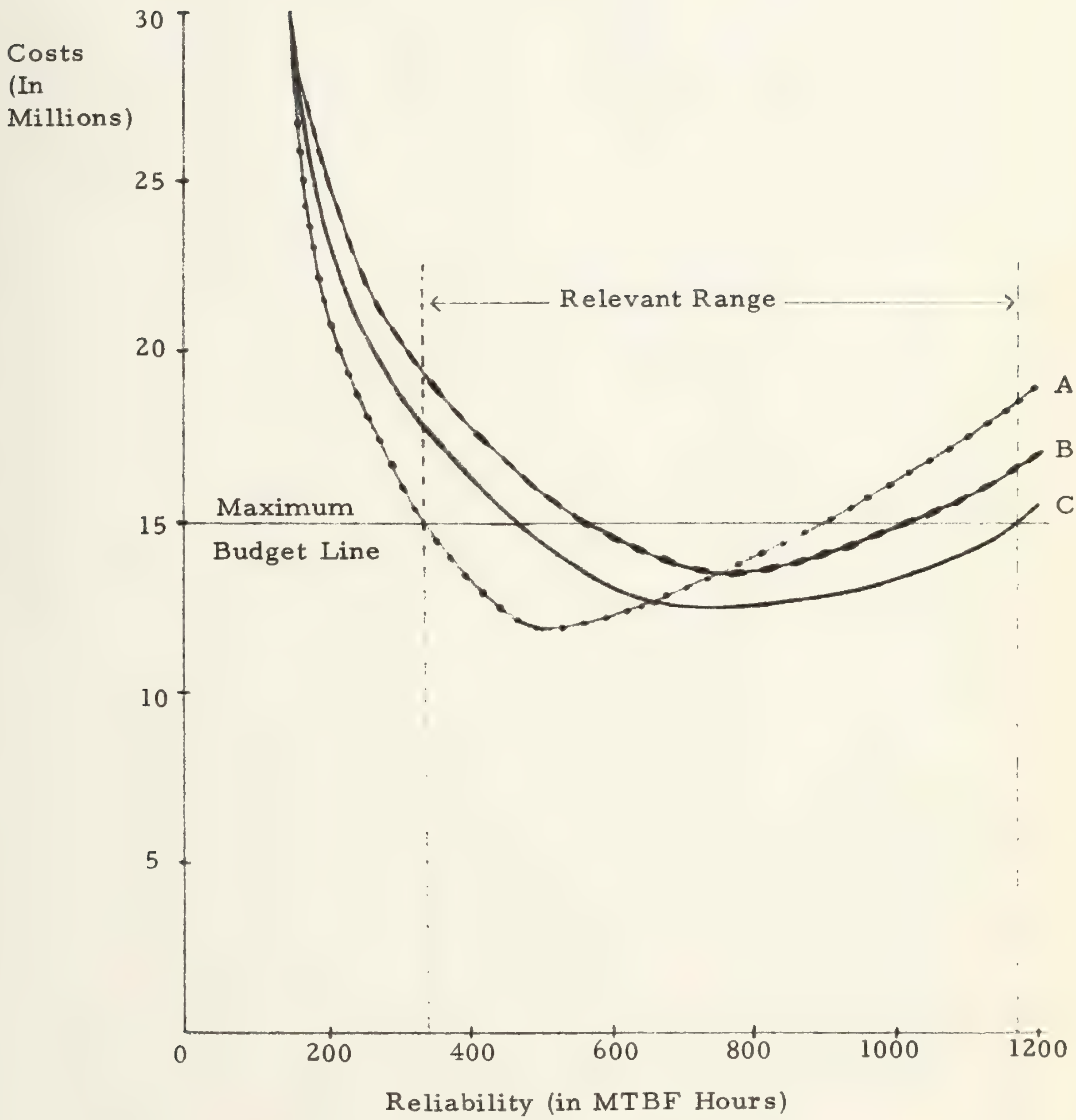

Fig. VII-5 -- Comparison of optimum positions of Companies A, B, and C based on evaluation of bid information.

that at no point does the cost curve of Company B offer a position superior to that of the other bidders.

Based on these considerations the logistician negotiates with the three bidders based on their proposals for 1,000 ten year life cycle radios at a reliability level of 740 MTBF hours with the following summary results:

Company	Life Cycle Cost Estimate
A	\$13,300,000
B	\$13,500,000
C	\$12,500,000

With this basic data in hand, the logistician is now in position to make use of Bayesian statistical decision theory in awarding the contract. In order to proceed, however, it is necessary for him to develop a subjective prior probability distribution. He can then combine this with sample evidence to develop a posterior distribution, the expected value of which would represent the probability of the particular company being able to produce radios of at least 740 MTBF hour reliability. The technical competence of each contractor-bidder is a matter of extreme importance in a case such as this. The Bayesian procedure offers an opportunity for expert judgment to be inserted into the decision process.

On the basis of past experience with the operation of each

contractor's equipment, the operation of related equipment now in the field, the examination of all pertinent performance records, and the evaluation of supporting detail submitted by these contractors, the logistician and his staff now proceed to arrive at a subjective prior probability distribution. This is done after weighing all evidence in the following manner. First, the logistician will designate levels of attainment, which he designates by the heading p. This p actually stands for the maximum decimal level of 740 MTBF hours capable of being achieved by the bidder. The estimated probability of ability to achieve these respective levels, P(p), is then estimated as follows:

p	Company A P(p)	Company B P(p)	Company C P(p)
.80	.10	.10	.05
.90	.20	.25	.15
.95	.68	.60	.70
.99	.02	.05	.10

The interpretation of these figures is quite straight forward. In the case of Company A, for instance, the logistician and his staff have estimated, after reviewing all available evidence, that there is a probability of only .10 (or one chance in ten) that the company can produce radios of at least 740 MTBF hours reliability a maximum of 80 percent of the time. Similarly there is estimated to be a probability of .20 that the designated reliability level can be attained a

maximum of 90 percent of the time. Similar interpretations can be made at the .95 and .99 levels of p for Company A. These meanings also hold for the figures indicated for Companies B and C. The logistician should finally review the distributions to be certain that whatever differences may exist among the companies at each level of p are intended.

The next step for the logistician is then to obtain relevant sample data. Assume now that the logistician is able to consult the Design Evaluation Group and an appropriate test program is devised.[9] It may be possible to consider the current test as being similar to that previously conducted on related equipment. If so, the logistician may be able to feel even more confident about his probability distributions. Based on the test plan, twenty-five critical components representative of the company's ability to produce the radio in question at a reliability level of 740 MTBF hours are selected at each plant and tested with the following results:

	Company A	Company B	Company C
Items tested	25	25	25
Items passed	24	23	24
Percent pass	96	92	96

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[9]See Chapter IV, supra, for a discussion of the need for such a body, readily accessible to the logistician.

The logistician now has a life cycle cost estimate, representative sample data and a prior probability distribution for each bidder. Making use of the binomial distribution as described in Chapter IV the logistician can then calculate expected values of the prior probability distribution by weighing sample and subjective data:

Company A

p	P(p)	Prior E(p)	Test p	P(T=24)	P(p/T=24)[10]	Posterior E(p)
.80	.10	.08	.024	.0019	.007	.006
.90	.20	.18	.199	.0358	.128	.115
.95	.68	.65	.365	.2373	.851	.808
.99	.02	.02	.196	.0039	.014	.014
	1.00	.93		.2789	1.000	.943

Company B

p	P(p)	Prior E(p)	Test p	P(T=23)	P(p/T=23)	Posterior E(p)
.80	.10	.08	.071	.0057	.029	.023
.90	.25	.23	.266	.0612	.306	.275
.95	.60	.57	.231	.1317	.659	.626
.99	.05	.05	.024	.0012	.006	.006
	1.00	.93		.1998	1.000	.930

Company C

p	P(p)	Prior E(p)	Test p	P(T=24)	P(p/T=24)	Posterior E(p)
.80	.05	.04	.024	.0010	.003	.002
.90	.15	.14	.199	.0279	.095	.086
.95	.70	.67	.365	.2446	.835	.793
.99	.10	.10	.196	.0196	.067	.066
	1.00	.95		.2931	1.000	.947

[10] As before, this is read "The probability of p given that twenty-four items out of twenty-five passed."

These results may then be summarized:

Company	Total Life Cycle Cost	Expected Value of Ability to Manufacture Radios at 740 MTBF Hours
A	$13,300,000	.943
B	13,500,000	.930
C	12,500,000	.947

All companies meet the established criterion of an expected level of manufacturing ability at 740 MTBF hours of at least 93 percent. Therefore the logistician would recommend that Company C be awarded the contract. In this particular case, the award company also had the highest expected manufacturing ability. Should this not have been the case, the logistician, in general, would have chosen that company whose expected manufacturing ability value at least equalled the established minimum, and whose indicated total life cycle cost was lowest. As previously mentioned in Chapter IV, the logistician may wish to conduct a sensitivity analysis to see how results change as slight adjustments are made in prior probability distributions.

It is also important to note that the Bayesian procedure followed above need not be considered ended once the contract is awarded. A continuing test program, as required by ILS procedures, would provide opportunities to further update the posterior distribution determined above. Should the indicated level of manufacturing ability ever

fall below 93 percent, the government would have strong reason to consider default of the contract and to take appropriate action. It is thus quite clear that the contractor's quality control procedures must be evaluated continually during the development and manufacturing phases.

Implications. -- Something in excess of $40 billion of the Department of Defense's budget each year goes for procurement. Any benefit realized from the adoption of a procedure such as that indicated above could have a significant pay-off. At the very least, the decision-maker would have a better basis for contract award than a simple comparison of contract bid prices. In order to carry out the procedures indicated in this chapter, however, proposals received from contractors should be required to show:

1. All cost elements included in the calculations, and the methods used and assumptions made in their calculation.
2. The methods used in predicting reliability.
3. Any supporting data from prior performance records.
4. The recommended test program by which the bidder would intend to demonstrate his manufacturing ability. The Design Evaluation Group may then choose to accept this or require additional procedures.

Military contractors have recently been initiating programs of life cycle costing in order to make design decisions and to make

competitive contract bids. This case example has shown how the ILS logistician can make better use of this data to allocate resources in a more efficient manner.

VIII

SUMMARY AND CONCLUSIONS

> These attributes of weapons acquisition preclude reliance on anything like a conventional market system for the procurement of advanced weapons, evoking instead what is best described as a nonmarket, quasi-administrative buyer-seller relationship. In this nonmarket environment the automatic guides and restraints provided by the market's "invisible hand" are absent. To replace them the government must deliberately structure its relations with contractors in such a way as to assure successful weapons program execution.[1]

As has been noted many times within this study the Department of Defense in allocating scarce economic resources is not subject to the same forces as influence firms in the private sector of the economy. The free market mechanism does not operate to provide a clear competitive signal to the military decision-maker to guide him in the acquisition of productive inputs nor does it evaluate the worth of the system output. Yet allocation decisions must and, in fact, are being made. Because national defense is a public good which must be provided by government if it is to be supplied at all, efficient allocation

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[1]Scherer, The Weapons Acquisition Process: Economic Incentives, p. 2.

of resources by DOD must therefore be determined by appropriate nonmarket means whenever possible.

The purpose of this study has been to examine certain theoretical concepts from economics, statistics and management science which have been found to have application in the private sector of the economy. The main thesis of this study has been that several of these concepts can contribute to an improvement in the military resource allocation decision-making process. There is, of course, full recognition of the fact that not all of the practices used by business decision-makers can be transferred from the private sector with equal effectiveness. Evidence has been presented, however, that certain concepts and procedures such as indifference curve and marginal analyses from economic theory, Bayesian statistical decision theory, inventory theory and cost-effectiveness analysis can be useful to the military logistician.

This study has taken as its setting the Integrated Logistic Support management concept which has been formally established by DOD directive. ILS is considered herein to be composed of ten "elements" required to insure the most economic yet effective support of a particular system or equipment throughout its life cycle. DOD implementing directives also provide for recognition of the responsibility of designated Acquisition Managers and logistician

assistants to direct the actual operation of ILS.

The specific elements of ILS are not new. They have, in fact, existed in some form as long as military operations have required logistic support. But because modern weapon systems have become so complex and costly many of the procedures and concepts of the recent past are no longer adequate.

Contributions From Economic Analysis

Because an economic problem exists whenever a resource allocation choice is required from among available alternatives (none of which would be as preferred as some unavailable alternative), economic theory can aid the logistician in making his allocation decisions more effectively. In the coming era of increasingly more stringent defense budget constraints, in fact, it will certainly be necessary for those in charge of military procurement and development programs to be able to demonstrate to appropriate authority that decisions are being made on a more economically efficient basis.

Relevant economic considerations discussed in this study include the important concepts of opportunity cost, discounting to present value, and marginal and indifference curve analysis. Concerning the idea of opportunity cost, the military logistician must recognize that the true cost of resources used in an ILS application is represented by the value of the product which is sacrificed because these resources

cannot be used in alternative applications. The strict use of outlay cost as a guide to decision-making may therefore be misleading.

In evaluating system alternatives which involve streams of life cycle costs and benefits occurring in different years, it is necessary that these costs and benefits be discounted to present value in order for meaningful comparisons to be made. There is at present no one discount rate used by all Federal agencies nor, indeed, is there even a uniform requirement that one be used at all. The year of occurrence of a cost or benefit is, however, important and should be formally recognized. Present value tables are widely available and should be made use of by the logistician.

The concept of marginalism can be as important in the public sector as in the private, although perhaps more difficult to apply. Thus it can be shown through the process of differential calculus that the economically optimum level of capability of a weapon system is to be found at the point where the marginal value received from moving to that level of capability is just equal to the marginal cost thereby incurred. Military worth is obviously difficult to quantify. Yet the logistician must bear in mind this theoretical ideal in making resource allocation decisions in order to avoid gross errors.

Indifference curve analysis and general microeconomic theory can be used to demonstrate how two valuable ILS inputs can be combined so as to obtain the highest possible output. Such

analysis requires that the logistician bear in mind the production function which, given the existing state of technology, indicates the maximum output technically possible from input combinations. Constant output quantities can be represented graphically as a family of isoquant curves. Inputs are then shown on both axes. The slope of the isoquant curve is determined by technical substitutability of the inputs. In order for an economic choice to be made, however, meaningful constraints may be represented by input cost and a limited budget. To the above graphical analysis, then, a budget line may be added, its slope determined by the ratio of the marginal costs of the two inputs.

Determination of an optimum economic position involves choosing from among equally efficient positions as represented by the isoquant curves. The optimum position for the logistician could be represented by that point at which the maximum available budget line becomes just tangent to the highest availability isoquant, or, alternately, where the lowest acceptable isoquant becomes tangent to the lowest possible budget line. The principles involved in this type of analysis can be extended to a problem involving many inputs by simply moving from plane geometric analysis to the use of calculus. In Chapter VII it was demonstrated how this basic analytic framework could be revised to be more immediately useable by the logistician while still retaining its essential properties for evaluation.

In view of these considerations, then, it can be seen that a new look at military logistic practices is in order -- a look in which it is essential that management, from the outset, should "think economics." In the past, as one writer has noted, "...the overriding consideration in the prognosis for any given system acquisition intention is the degree of predisposition for or against it in [the Office of the Secretary of Defense]."[2] While this may still be true in the future, it is nevertheless likely that this predisposition will tend more than ever to be based on economic considerations, once basic objectives have been established through the political process.

Bayesian Statistical Decision Theory

Because of past training, experience and access to relevant cost and performance data, the military logistician possesses a valuable reservoir from which the ingredients to form a valid subjective opinion can be drawn. This opinion, although admittedly subjective, can be intrinsically as valuable as any strictly objective evidence which the logistician can obtain. A basic systematic procedure has, however, been lacking in the past for combining subjective and objective information by the logistician. If a mechanism for introducing subjective evaluation earlier in the decision process

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[2] M. Eckhart, Jr., "Another Kind of Strategy," United States Naval Institute Proceedings, September, 1969, p. 29.

could be developed, centralization of management decision-making at the higher levels of DOD might be considered less necessary. The advantage of pushing the decision-making process down the channels of command is that only in this manner can the particular expertise and experience of the logistician be fully utilized. For example, procurement awards are customarily made at present on the basis of bid price at times backed up by certain test results. Valuable subjective opinion available at lower levels has generally not been brought to bear in this process in any meaningful fashion.

Bayesian statistical decision theory, which views probability as a series of subjective weights or degrees-of-belief, can be extremely useful to the ILS logistician by providing a means for bringing all available and relevant information to bear in the economic solution of a problem of resource allocation. Of course, unless the logistician can make a meaningful contribution to the decision-making process not much benefit will be realized from his use of this analytic tool.

Calling on his reservoir of data, the logistician can proceed to logically develop a subjective prior probability distribution based on his own degrees-of-belief concerning the problem at hand. In many cases, this subjective prior distribution can be based on information obtained from past tests on similar or related equipment, often produced by the same contractor-bidders now under evaluation. This

should certainly tend to enhance the accuracy of the prior distribution as well as to help insure compatibility with current test results.

Due to the random manner in which much of the equipment with which the logistician is concerned fails, the binomial distribution can be logically used in combining the subjective and objective data. This process can be facilitated by recourse to standard published binomial distribution tables. Once both types of information have been combined (a procedure illustrated in Chapters IV and VII), the expected value in the revised or posterior distribution can be used to assist in evaluating more efficiently each bidder's proposal. The method of combination and the expected value approach used in this study is, of course, only one of several possible. Due to its ease in understanding and use, however, and because of the random failure pattern of many support items, it would appear to be highly appropriate for use in the ILS environment.

Inventory Control and the Influence of the Customer Service Level

Inherent in the concept of logistic support is the realization that inventories of reserve material must be maintained. It has long been recognized in private business logistics that one of the most significant costs involved in inventory is that of holding or carrying it. Indeed, it has been widely estimated in business that these costs seldom run less than 25 percent per year of average

inventory value. The chief components of this holding cost are interest, obsolescence and depreciation. In terms of how these particular components are valued, military holding costs appear to be understated. The outcome of this is that support inventories may be larger than are economically desirable with detrimental effects on efficient resource allocation. The interest rate widely used by Navy inventory managers for example is 4 percent. Such a figure is highly unrealistic in today's economy. A more realistic attempt should therefore be made by DOD to assess the current "cost of capital." This should include a consideration of both the "pure" interest rate and an additional additive factor appropriate for the unique risks involved with highly sophisticated military systems.

Another frequently understated element of military inventory holding cost is obsolescence. Due to the rapid advance of technology many systems are obsolete within a relatively short time after delivery to operating units. This fact is frequently not adequately reflected in holding cost and economic lot formulas used by inventory managers. A straight line decline in value due to obsolescence is often used on the basis of an arbitrary "shelf life" calculation. This calculation may not take into account the fact that a perfectly useable item can be on the shelf for several years after it becomes obsolete. As for depreciation, it generally is not

recognized in holding cost formulas as an entity separate from obsolescence. Considering the large capital investment involved in many modern inventory components, it would appear that depreciation should be recognized as a significant and distinct component of holding cost.

In view of the above, the frequently used inventory holding cost rate of 15 percent per year of average inventory value would seem to be quite inadequate. If anything, due to the higher risks and uncertainties involved, the cost of holding military inventory should be considerably higher than the 25 percent per year minimum figure commonly accepted in private industry.

Provision of service to the customer is, of course, the prime mission of the military logistician. In order to more fully appreciate the needs of the system-user customer, it is doubly important that he participate in initial design decisions. In addition, he must have clear channels of communication to the inventory managers through cognizant element managers so that he may be able to provide guidance concerning "protection levels" established by the inventory managers on items of direct interest. Customer service levels (levels of system or equipment availability or reliability -- whatever the logistician is trying to insure) will certainly suffer if the inventory manager places too low a protection level criterion on reserve stock. If the inventory manager feels that such steps are unavoidable due to budgetary constraints, the

system logistician should be immediately notified so that any higher level action deemed appropriate might be initiated. The situation should not be allowed to develop, as is now possible, wherein the fact that an inadequate level of protection has been assigned to an item becomes apparent to all concerned only after the item in question is urgently required.

In short, then, military logistics management can profitably learn from business logistics practices. The somewhat narrow concept now being followed should be broadened to include relevant procedures that are available from the private sector.

ILS and Cost-Benefit Analysis

Cost-benefit analyses have been successfully used in a number of governmental applications. In general, however, these applications involve situations in which both benefits and costs are relatively easy to isolate and value. Unfortunately, such a situation does not generally prevail with national defense programs, the choice of which is often subject to a degree of political influence. Full-blown cost-benefit studies are thus often rendered virtually impossible due to the immeasurables involved. By accepting the politically-decided goals or objectives as the benefits to be attained, however, the logistician can effectively employ the more limited technique of cost-effectiveness analysis. The objective of such

analysis should be to indicate how best to either (1) maximize system effectiveness given a relatively fixed budget, or (2) reach a particular level of effectiveness with the least expenditure of resources as measured by associated costs. In the past, such analyses have at times been performed largely to support pre-determined preferences. To be correctly used, however, all relevant factors must be objectively considered. As many of these factors should be logically quantified as possible. Those that cannot be quantified should be presented to the decision-maker for subjective evaluation indicating trade-offs available. Cost-benefit type studies can thus be considered of importance to ILS in large measure because they help to focus attention on factors that might otherwise be overlooked.

Many of the decision problems which the logistician faces can be considered as involving a general type of cost-effectiveness analysis. His first responsibility should be to participate in design decision so that he will be in position to clearly understand the objectives or goals (benefits) to be achieved and the level of customer service required. He may then proceed to identify as appropriate those officially designated elements of ILS which may be involved, and then to value them, considering trade-offs possible. Having completed this analysis, he would then be in position to recommend the most cost-effective and economically efficient position possible based on objective information

then available. One example of how this might be approached has been developed in Chapter VII.

Recommendations

Based on the analysis described in this study the following recommendations have been offered to aid the logistician to fulfill his role as envisioned by DOD with greater effectiveness:

1. Potential ILS logisticians should, in the course of general management training activities, receive greater exposure to basic concepts in economic and statistical theory. This could be accomplished by including appropriate courses and training activities in the curriculum of the several logistics and management training schools now in existence. Topics to be covered would include:
   a. Basic microeconomic theory with applications to military resource allocation problems.
   b. Elements of statistical decision theory including the use of probability.
   c. Inventory theory.
   d. Cost-benefit analysis (including cost-effectiveness evaluation).
2. The logistician should, in fact as well as in theory, be accorded a role in the initial design decision process. Only

through such participation will he be able to present timely advice concerning support cost-reliability trade-offs as well as gain insights into the levels of customer service that may be required. The Chief of Naval Material should have responsibility for insuring that such action is taken.

3. Clear and rapid lines of communication need to be established between ILS logisticians and element managers. Contacts now being made are frequently untimely and sporadic in nature. Here again the Chief of Naval Material should have the responsibility for drafting appropriate directives.

4. A "Design Evaluation Group" should be established as an integral part of the Naval Systems Commands, readily accessible to the logistician, so that technical problems relating to such matters as test programs and procedures recommended by contractors can be evaluated and appropriate tests of design reliability and effectiveness devised. The establishment of such a group should be proposed by the Chief of Naval Material as a joint venture with the Systems Commands.

5. The "budget" of the logistician should be conceived of as encompassing all elements of cost regardless of funding appropriation, year of cost incurrence, or office of final accounting responsibility. It has been noted, for instance, that "Lower

level managers are 'charged' with only a small proportion (20-30 percent) of the resources they actually consumed. Consequently, there is a tendency to over-consume other seemingly free goods (70-80 percent)."[3] Appropriate changes should be made by DOD to its Planning-Programming-Budgeting System so that budget justifications can be structured in such manner for presentation to Congress.

6. Uniform accounting standards should be developed and made mandatory for defense contractor use so that alternatives can be more meaningfully compared, the true cost of defense contracts ascertained, foot-in-the door bidding opportunities reduced, and duplication of charges eliminated. One company official has stated regarding this problem as it affects logistics that

> The major parameter of logistics is cost. At the moment there are insufficient data available in standard references to assure that all competing contractors will use the same basic cost references. The only solution to offer at this moment is to proceed post-haste to develop such a common source to permit reasonable comparison of cost-of-ownership.[4]

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[3] Jack W. Carlson, "Comments on Institutional Structures and Defense Spending," in Issues in Defense Economics, ed. by McKean, pp. 256-257.

[4] John E. Losee, "Logistics Development During the Conceptual and Contract Definition Phases for USAF Programs," presentation to the 1967 SAE/AIAA/AFME Reliability and Maintainability Conference, Cocoa Beach, Florida, July 17-19, 1967.

The General Accounting Office should make an appropriate report to the Congress in this regard so that DOD may then be able to understand the will of Congress on this important subject.

7. All requests for quotes issued by DOD activities to potential bidders on systems or major items of equipment should require the submission of cost-reliability trade-off data which backs up their proposals. This would serve as an important means of proposal evaluation by the Design Evaluation Group and the logistician. The Chief of Naval Material should institute action to see that such data is required in Navy contracts.

8. More formal recognition should be made of the fact that the demonstration of high reliability by a contractor during the research and development stage of system procurement is important, but this must also be carried over into the subsequent manufacturing phase as well. The Chief of Naval Material should, therefore, insure that contracts require strict monitoring of the contractor's quality control program as production proceeds. Operational commands must then, upon delivery, be especially careful to insure that high maintenance standards are maintained in accordance with original contract specifications. The Chief of Naval Operations should issue appropriate instructions to this effect.

9. Finally, the fact must be recognized and made use of that the logistician has professional expertise which can make his subjective judgment potentially valuable and useful. Following the approach recommended in this study would permit this judgment to be put to use in a systematic manner.

Assuming the above courses of action are taken, the logistician will be able to allocate scarce economic resources in a more efficient manner. This increase in efficiency should be achieved by evaluating potential cost trade-offs so as to optimize output within over-all budget constraints, deciding on the best possible combination of inputs by examining the effects of different combinations on total system performance.

Concluding Comment

The ILS logistician as a manager of valuable resources must be interested in the most economically efficient allocation of these resources possible. The overall objective of ILS, in fact, should be to attain an optimal mix of system effectiveness and related support costs. The concepts and procedures developed in this study should significantly aid in the attainment of this objective. In particular, logistic support contract proposals should be evaluated more effectively "price and other factors" considered. Integrated Logistics

Support is in effect a philosophy established as an operational concept of resource management. What remains now is for the ILS logistician "...to devise the techniques necessary for exploiting the full potential and promise of the concept of Integrated Logistics Support."[5] This study has been carried out as a contribution toward realizing that goal.

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[5]Giordano, "Logistical Implications of Weapon System Design Decisions," p. 207.

APPENDIX A

DEFENSE AS A PUBLIC GOOD

A public good may be defined as any good or service for whose supply the political process is required because "the pricing system of the market cannot deal with all the tasks that must be met in order to operate a sound economy and a healthy society."[1] In the supply of some kinds of goods and services, then, reliance on the competitive market could result in undersupply, or no supply at all. The basic problem is that these goods and services are such that they must be provided collectively to the community or nation. They do not lend themselves to being divided up into units to be sold separately to individual consumers. The consumption of the good or service by one individual in no way lessens the amount available for consumption by another and the marginal cost of supplying an additional consumer is zero or nearly zero. It is difficult to exclude anyone from the benefits of consumption, at

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[1]Richard A. Musgrave, "Principles of Budget Determination," in Public Finance & Fiscal Policy, ed. by Joseph Scherer and James A. Papke (Boston, Mass.: Houghton Mifflin Company, 1966), pp. 3-4.

least in any manner tolerable in our society, and in fact attempts at exclusion might even raise the total costs of providing the good or service. There is, therefore, no reason for anyone to reveal his true preferences since he will be able to consume the good or service whether he voluntarily pays for it or not.

Consider the example of an interstate highway. This is not a "pure" public good, since exclusion would be possible. The example can be used, however, because "externalities," or benefits for which the producer cannot charge, are present. Attempts to supply the service entirely through the market mechanism would result in undersupply assuming net benefits to be positive. To be useful, the highway must generally extend over areas many people wish to travel. If the cost of building the highway were to be obtained entirely from these users, it would be necessary to make the highway a toll road or to devise some other type of user-fee system such as electronic sensing since in no other way could persons be barred who did not wish to contribute more than the amount represented by gasoline tax. In this example, the cost of collecting tolls or installing the user-fee system could also raise the total cost of providing the service. Some economists have, in fact, pointed out that when external economies are present, the market mechanism may not only provide less of the good or service than is optimal, but will also make

society pay more for the suboptimal quantity than if it were supplied by the government.[2]

Figure A-1 illustrates how an undersupply of a public good or service can occur. Assume that the demand curves of two individuals for a particular public good are represented by the lines AB and A'B'. If a certain level such as OE, is produced, each and every person receives this same level of output. Therefore, in the case of a public good, any potential output is available to anyone and thus the appropriate construction is to set the quantity and then see what can be extracted from the market, i.e., sum demand vertically. The negative slopes

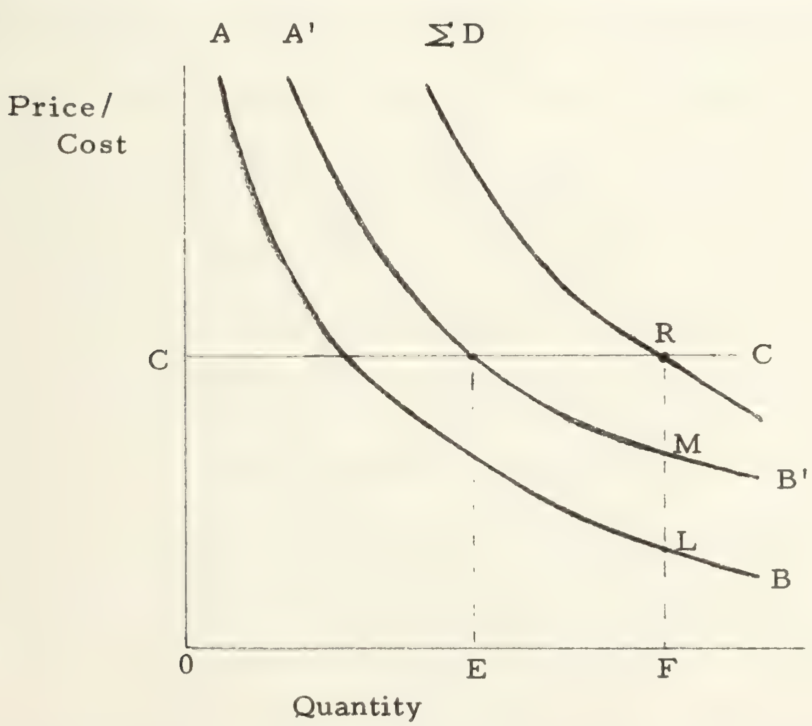

Fig. A-1 -- Illustration of the possibility of undersupply of a public good or service through reliance on the market mechanism.

[2]Mancur Olson, Jr. and Richard Zeckhauser, "Collective Goods, Comparative Advantage and Alliance Efficiency, in Issues in Defense Economics, ed. by McKean, p. 37.

of the demand curves indicate that marginal worth decreases as quantity supplied increases.[3] Now let CC represent the good's average cost curve, its zero slope indicating a marginal cost equal to average cost. Since, according to the principles of welfare economics, price should equal marginal cost, OC represents the price to be charged.[4] Production would thus theoretically take place at OF since the intersection of marginal cost (and price) with total marginal worth as measured by demand is at R. Now the two individuals might collectively desire this quantity of the public good or service but find individually that its marginal worth to them is below marginal cost, and hence not wish to purchase it at price OC. In the above example, in fact, FL represents what one person is willing to pay for the Quantity OF and FM what the other is willing to pay. Demand at the price OC, where price = marginal cost = marginal worth to at least one individual is, however, at OE. At OE, one of the individuals would not be willing to pay the market price yet could not be excluded from benefiting since markets do not exist to extract different prices. One individual would thus pay the market price and the other would pay nothing. Hence the quantity EF would not be produced by the market even though it is theoretically

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[3]See Watson, Price Theory and Its Uses, pp. 62-63 for a discusstion of the principle of diminishing marginal utility (worth).

[4]Ibid., p. 128.

desired.

National defense, as noted in Chapter I, is perhaps the best example of a public good. As Due puts it:

> ...benefits in the form of protection from foreign invasion, seizure of foreign territory or prevention of invasion of friendly countries accrue indivisibly to the entire community, and no one can be prevented from benefiting. Private production is therefore impossible.[5]

Since the market mechanism cannot provide the desired supply of national defense, a political process is necessary. Preferences can then be revealed either through direct voting for various programs, or the election of representatives pledged to certain courses of action.[6] In such a manner, society is able to translate individual preferences into provision of public goods and services. The role of the economist in this is to contribute to the judgment and perception of public officials at all levels of the decision-making process.

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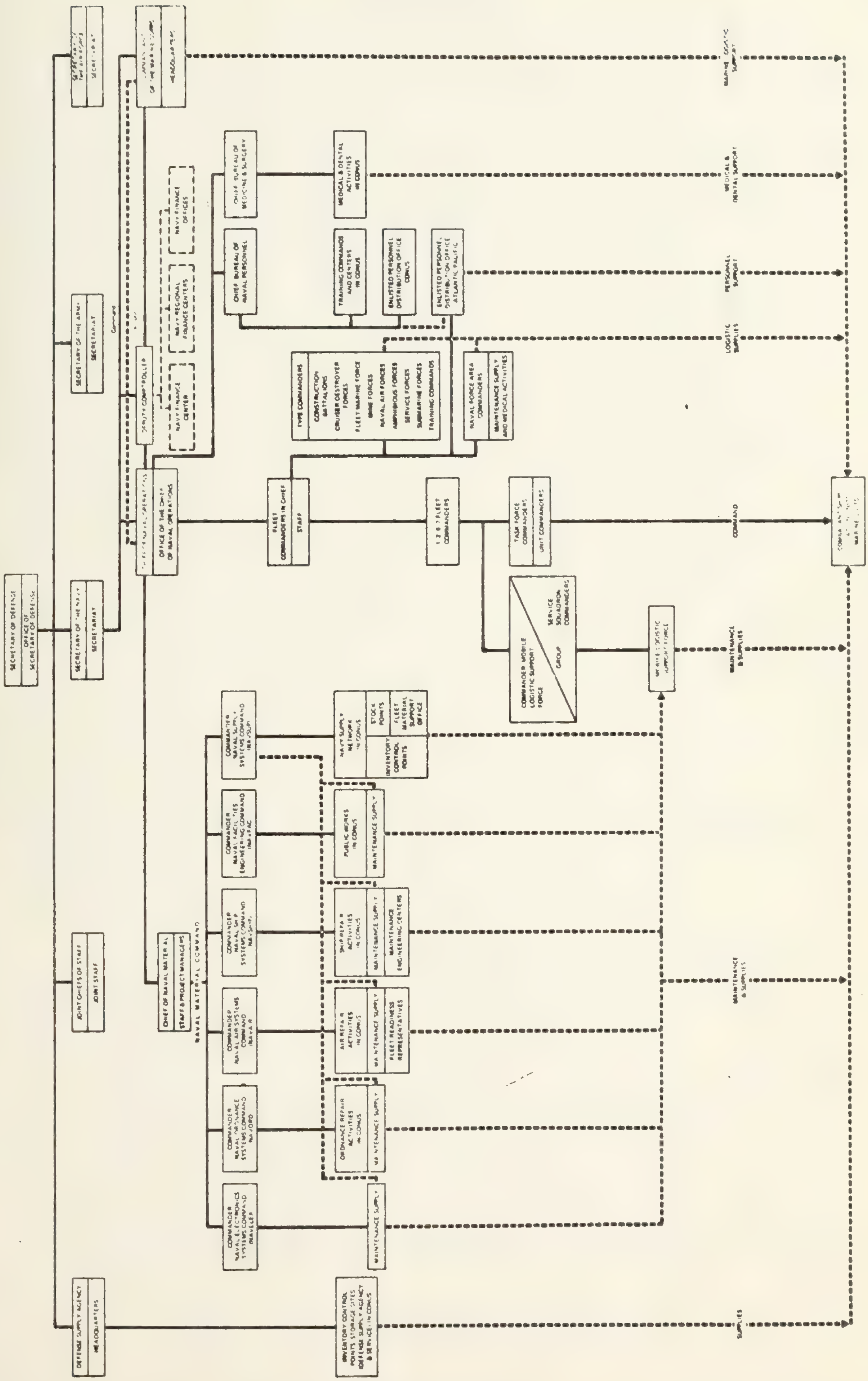
[5] Due, Government Finance: Economics of the Public Sector, p. 9.

[6] See the discussion of the basic logic of voting in Anthony Downs, An Economic Theory of Democracy (New York: Harper & Brothers Publishers, 1957), pp. 36-50.

APPENDIX B

SUMMARY OF ORGANIZATIONS ENGAGED IN LOGISTICS SUPPORT



Source: U. S. Navy Supply Corps Newsletter, January, 1969, p. 61.

APPENDIX C

PURPOSE AND OBJECTIVES OF THE ILS CONCEPTS TRAINING COURSE

Purposes:

1. To provide an effective and meaningful understanding of key concepts underlying Navy Integrated Logistic Support (ILS).
2. To indicate the manner in which the Secretary of the Navy requires the utilization and application of these concepts to the acquisition process.

Objectives:

1. To provide relevant course material which will have significant residual value beyond the course.
2. To document the essential concepts of ILS and their application throughout the life cycle of modern Navy systems.
3. To illustrate the principal parts of the weapon system acquisition process, their inter-relationships, and the importance of knowledgeable personnel in the direction of logistic support programs.
4. To indicate the relationship among major Department of Defense

implementing directives within the Department of the Navy.

5. To emphasize the application of ILS concepts, not only to major systems that undergo Concept Formulation/Concept Definition phases, but also to those systems and equipment representing the majority of Navy acquisitions, which do not undergo this process.
6. To stress the importance of considering ILS as an everyday function of extreme importance to the success of the military system decision-making process.
7. To actually apply concepts related to the use of ILS techniques.
8. To encourage the idea that uniform ILS practices should be used throughout the Navy wherever appropriate.
9. To transmit a reference bibliography.
10. To help improve manpower utilization by supporting the idea of career development in the field of ILS.

APPENDIX D

PRINCIPLES OF INTEGRATED LOGISTIC SUPPORT

1. Requirements for integrated logistic support shall be included in systems or equipment development studies, plans, specifications, requests for proposals and contracts.

2. Preparation of integrated logistic support plans shall be accomplished concurrently with development of plans for development, test and evaluation, and procurement.

3. Integrated logistic support shall be based upon a documented engineering analysis of maintenance and operational requirements inherent in the equipment design and the plan for use.

4. Requirements for integrated logistic support shall be "tailored" to fit the system or equipment to which applied.

5. Systems and cost analysis organizations and programs shall support and apply the policies and principles of this Instruction.

6. Integrated logistic support programs shall include maintainability requirements and utilize reliability program inputs.

7. Test and evaluation programs shall concurrently test and evaluate the configuration, integration, performance and effectiveness of the

integrated logistic support resources provided to support the systems or equipment under test.

8. The integrated logistic support program shall produce basic computer library file inputs and information products in support of management information systems, i. e., configuration accounting, readiness reporting, inventory management, maintenance data collection, performance analysis and cost accounting.

9. Management information systems shall provide data to monitor the performance of the integrated logistic support system and provide data to generate refinements and improvements.

10. Responsibility for integrating the logistic support of each system or equipment shall be assigned to a specifically designated individual.

Source: SECNAV Instruction 4000. 29, Development of Integrated Logistic Support for Systems and Equipment, Enclosure (2).

APPENDIX E

DEFINITIONS OF ILS ELEMENTS
(Excerpts)

Maintainability and Reliability:

Maintainability is an expression of the probability of equipment being restored to operating status within allowable time limits using available test equipment, facilities, personnel, spare parts and procedures. Reliability is the probability that an equipment will continue to function correctly for a specified period of time without failure under a prescribed condition of use.

Both maintainability and reliability are included as maintenance preventive characteristics in equipment design and support resources requirements. Maintainability and reliability goals must be integrated into the equipment and support system design through requirement and contract specifications. The specification requirements must be stated early in the concept formulation phase.

Surveillance over changes in both design and support is required to prevent degradation of maintainability and reliability. Demonstrations with the equipment must be conducted to see that

requirements are met. The demonstration results are analyzed and tradeoffs conducted to improve system design and support. These early tradeoffs result in a continual narrowing down of configuration ideas until a firm production baseline is established. Because paper and prototype changes are relatively inexpensive, maximum emphasis must be placed on maintainability and reliability prior to establishing this baseline.

Maintenance Planning:

Maintenance planning establishes concepts and requirements for each level of equipment maintenance to be performed during its useful life. As such, maintenance planning defines the actions and supporting requirements necessary to maintain the designed system and equipment in its prescribed state of operations. Maintenance functions include checkout, servicing, crew augmentation, status monitoring, inspection, fault isolation, replacement, modification and overhaul. The degree to which these various functions are to be performed by organizational, intermediate, or depot level maintenance must be spelled out. The use of contract maintenance should be considered. The maintenance plan responds first to readiness requirements and next to economies in the commitment of supporting resources.

Specific maintenance actions to be performed at various levels of maintenance and the resource requirements needed to support those

actions, are identified by systematic and detailed maintenance engineering analysis. This analysis is conducted concurrently with hardware design and is updated as design changes. Maintenance engineering analysis documentation provides:

The identification and description of tools and test equipment, facilities, personnel, spares and repair parts and technical data,

Quantification of most maintenance support needs by time and place,

Personnel requirements analysis by skill, type and number, and

Facilities loading to establish adequacy and utilization.

Support and Test Equipment:

The purpose of the support and test equipment program is to assure that the required support and test equipment is available to the operating forces and supporting maintenance activities in a timely manner. The ability to perform the required unscheduled and a scheduled maintenance depends on the adequacy of the support and test equipment identified or developed concurrently with the prime system and equipment. Support and test equipment consists of tools, metrology and calibration equipment, monitoring and checkout equipment, maintenance stands and handling devices which are categorized into special

(peculiar to the system under development) and common (commercially available or currently in the defense inventory). The support and test equipment program encompasses all life cycle phases.

Supply Support:

Maintaining operational readiness under diverse conditions of military use depends directly on the availability of the right supplies at the time and place they are needed. Supply support is an essential element of the logistics integration effort and is responsible for the timely provisioning, distribution and inventory replenishment of spares, repair parts, and special supplies.

Supply planning for spares and repair parts must be based upon technical inputs from maintenance planners and engineers (e. g., system/equipment utilization rate, operating hours, failure rates, required field repair rates, locations, and selected maintenance items critical to safety and mission accomplishment). This process requires support management attention through all phases of the equipment life cycle. Inventory management control depends upon current and complete knowledge of item status by configuration and location so that support management decisions can be made on a responsive basis.

Transportation and Handling:

The transportation and handling element includes the characteristics, actions and requirements necessary to insure the capability to transport, preserve, package and handle all equipment and support items. The functional requirements and actions are developed from operations and maintenance analyses, equipment design drawings, specifications and other documentation defining transportability criteria, handling equipment and procedures, and packaging and preservation needs. Requirements to be considered include:

Transportability and packaging criteria such as time, locations, duration, frequency, volume, safety, security and fragility;

Desired locations for transportation equipment and facilities;

Planned availability of existing system capabilities by quantity, volume and location;

Additional or special transportation and handling procurement requirements; and

Interfaces with other system design and support management functions.

These considerations require support management attention through all phases of the life cycle.

Technical Data:

The purpose of the technical data program is to provide for the timely development and distribution of technical data necessary to conduct operations, training maintenance, supply, modification, repair and overhaul of the systems and equipment. Technical data provides the link between personnel and equipment. It includes drawings; operating, maintenance and modification instructions; provisioning and facilities information; specifications; inspection, test and calibration procedures; instruction cards and equipment placards; special purpose computer programs and other forms of audio/visual presentation required to guide people performing operations and support tasks.

Technical data planning must be based upon information from equipment operations and maintenance planners (e.g., system/equipment use, design characteristics, operations and maintenance methods and personnel tasks, frequency and time to repair, supply provisioning and inventory items and procedures, etc.). Technical data considerations are involved in design and support trade-offs, tests, demonstrations, production, operations and maintenance.

Facilities:

The purpose of the facilities program is to assure that all required facilities are available to the operating forces and sup-

porting activities in a timely manner. The ability to perform the mission could depend on the adequacy of facilities provided concurrently with the prime system or equipment. Facilities planning is based on operations and maintenance analyses, equipment design drawings, specifications and other documentation necessary for defining types of facilities, locations, space needs, environment, duration and frequency of use, personnel interfaces, installation activities, training requirements, test functions and existing facility applications. Facilities planning requires support management attention through all phases of the life cycle to provide positive coordination with other program elements, particularly with regard to dates of need and construction program lead times.

Personnel and Training:

The personnel and training program defines the requirements for trained operations and maintenance personnel and training devices needed to support the program through all life cycle phases. A realistic estimate of current manning capabilities, in terms of both numbers and skills, must be made against the probable quantitative and qualitative manning demands of the system or equipment concepts under study. As hardware concepts are developed, design and support decisions must be made with due consideration for their impact on manpower and training requirements.

Personnel and training planners must progressively identify manning requirements for test and demonstration, operations and maintenance in the use environment. They must consider task categories and resulting optimum skill mixes needed to achieve or exceed readiness performance goals. Personnel requirements for operations and maintenance must be balanced against manpower availability.

Funding:

Successful ILS planning during all phases of the equipment life cycle requires management attention to the interface between the support element needs and defense budgeting and financing procedures. Because of their importance to implementing logistics support, budgeting and financing activities are included as a prime element of support management. Budgeting and financing activities should include the:

Early determination of logistics support funding requirements, which, together with experience factors from similar equipment programs, allow accurate forecasting of life cycle costs,

Accurate updating of forecasts for timely fiscal planning and apportionment of required research and development, investment and operating funds,

Allocation of available program funds to each logistics support

element based upon its justified need, with emphasis given to program schedule and task priorities, and

Accurate accounting of funds expenditures using work breakdown structure and measurement criteria to insure proper funds utilization and redistribution.

Management Data:

Defense activities use and support many information systems to meet separate technical management needs of organizations with differing development, support and operational missions.

Information and control systems interfacing with support management include: maintenance engineering and analysis control documentation; engineering test and demonstration records; program schedule and cost controls, such as pert or critical path; maintenance management and failure data; miscellaneous requirements forecasts, e.g., personnel, equipment, supplies, and facilities; configuration management; operational readiness support status, and supply management effectiveness reporting systems.

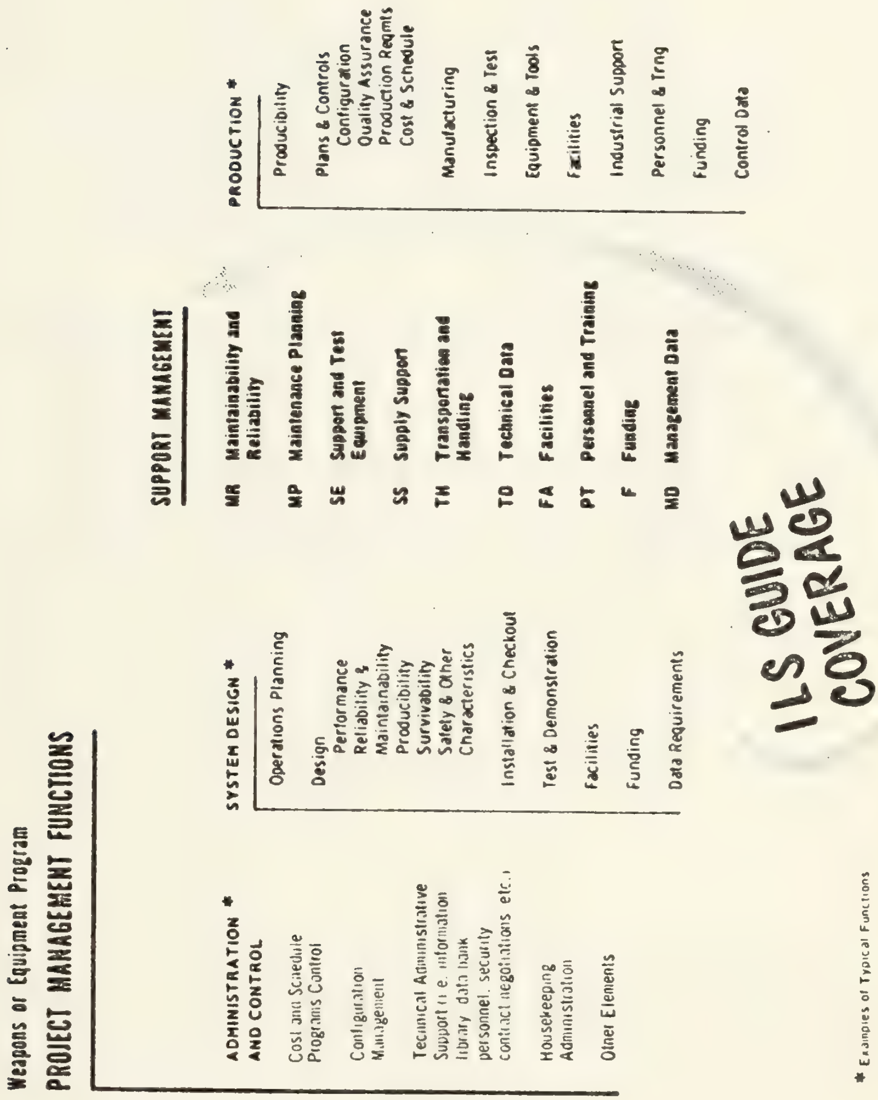
Early in the development phase of the acquisition life cycle, Support Management selectively identifies the extent to which the above information systems will be required during the item's life cycle, when they will be required and how and by whom the requirements will be met.

Data become useful information only when they are assembled into manageable aggregates for purposeful evaluation. When this can be easily done manually, time and costs can be reduced. When sampling/summary techniques can provide needed information on a one-time or periodic basis, redundant report processing is eliminated.

At the other extreme, the acquisition and operation of new and complex equipment may justify electronic data processing support. Here, standardization of data codes, use of available software, and new generation computer capabilities combine to make data-bank concepts attractive. This approach satisfies all the information requirements of the formal systems and also permits selective reporting of current data to functional support managers on an as-required basis.

Source: Department of Defense Publication 4100.35-G, Integrated Logistics Support Planning Guide for DOD Systems and Equipment, pp. 37, 47, 55, 63, 71, 79, 85, 93, 101 and 109-110.

APPENDIX F



Source: Department of Defense Directive 4100.35-G, Integrated Logistics Support Planning Guide for DOD Systems and Equipment, p. 4.

APPENDIX G

WEAPON SYSTEM LIFE CYCLE PHASE

SUPPORT PLANNING ACTIVITIES

Concept Formulation phase support planning activities begin with the definition of top level functions needed to satisfy operational capability, e.g., new mission, weapon system, or equipment. Trade-off studies are performed to find different means of satisfying those requirements which cannot effectively be satisfied by existing support capabilities. The best of these support programs are selected and included in the 5-Year Defense Program along with the prime equipment selection.

Contract Definition phase support planning activities are based on the logistics requirements in the system development plan. The technical requirements are grouped together with management planning criteria for inclusion in the request for proposal to contractors. Contractor proposals should be evaluated for: (1) the degree to which they meet or exceed minimum readiness requirements and other support specifications, (2) comparative credibility of life cycle cost estimates, and (3) demonstrability of specification goals and requirements. The

selected contractor support plan and detailed technical and management criteria for development phase planning are combined in a logistics support plan for inclusion in development phase contracts. Anticipated requirements for maintenance actions, equipment, personnel, training, spares, and data are identified. Development contracts must define equipment readiness (in terms of maintainability and reliability requirements) as well as other support requirements and constraints, schedules and controls, and subsystem and system demonstrations to be conducted for validation of all specification requirements.

Development phase support planning activities begin with the definition of more detailed logistics support concepts and resource requirements as the system/equipment design progresses. Logistics support personnel participate in design reviews and hardware tests and demonstrations. All resulting changes are evaluated by support element specialists for their impact on support requirements and functions. Design/support trade-offs are conducted. Program management approval based on these trade-offs results in establishment of a proposed product baseline configuration and release of initial production contracts.

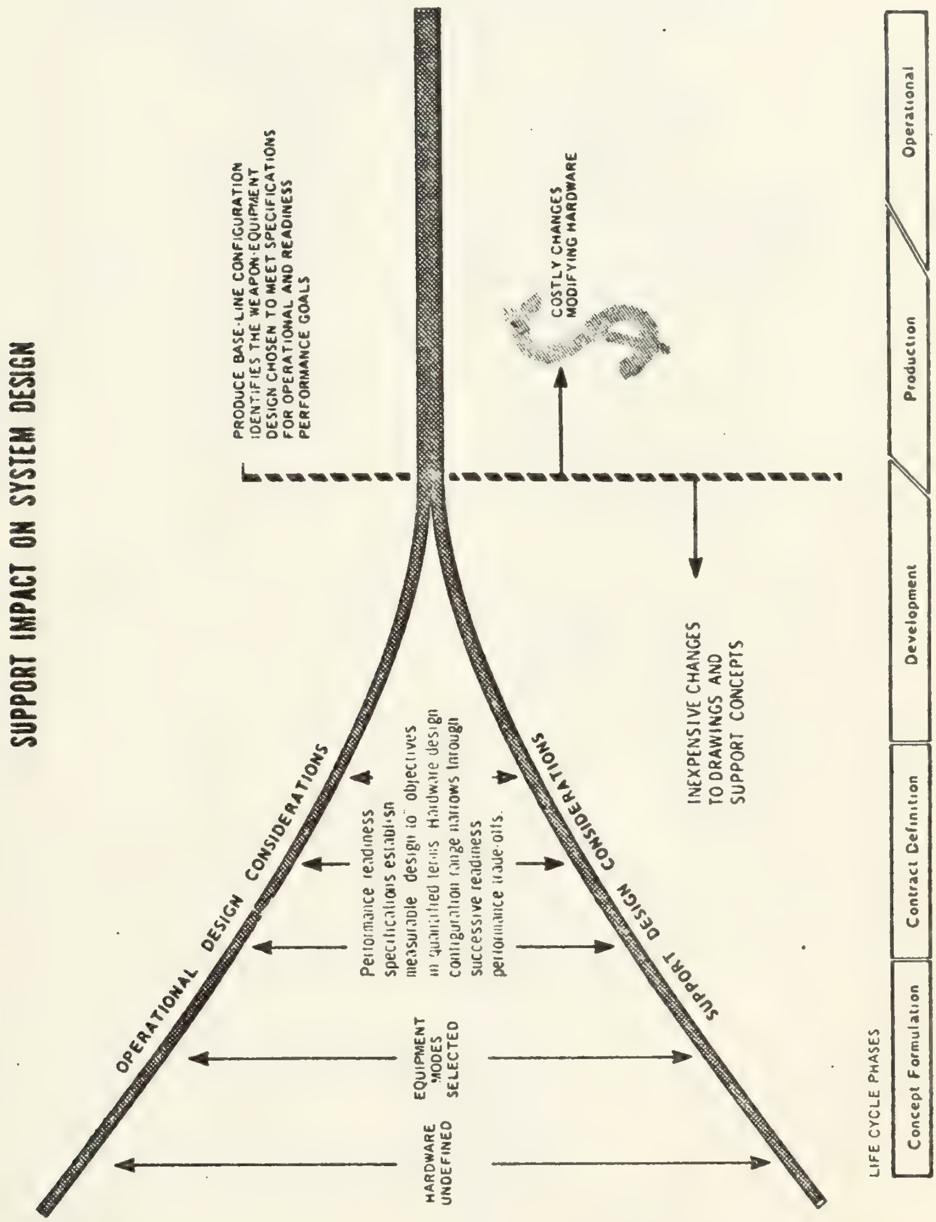
Production phase support planning activities start with the completion and release of detailed procurement specifications for hardware and

supporting items. Limited quantities of these resources are procured for test. A first article inspection is conducted. Service tests are conducted in a preplanned operational environment to verify user suitability and the achievement of support requirements. Deficiencies, found during test, are corrected by engineering change. The changes are evaluated for their impact on support planning prior to their incorporation into follow-on production items.

Operational phase support activities begin prior to delivery of initial production units to the first operating organization for suitability testing. All deficiencies are identified and evaluated by design/support trade-offs prior to making modification decisions. Equipment modernization or phase-out for technical reasons is dependent on advancements in the state-of-the-art, revised mission requirements and evaluations of the cost-effectiveness of maintaining existing inventories compared to replacement with better equipment.

Source: Department of Defense Publication 4100.35-G, Integrated Logistics Support Planning Guide for DOD Systems and Equipment, pp. 9-11 (excerpts).

APPENDIX H



Source: Department of Defense Directive 4100. 35-G, Integrated Logistics Support Planning Guide for DOD Systems and Equipment, p. 6.

APPENDIX I

DISCOUNT RATES USED BY FEDERAL AGENCIES

FISCAL YEAR 1969

Agency	Rate(s)	Rationale
Tennessee Valley Authority	4.5 to 5.5	Treasury borrowing cost, except for Power Supply where cost of money to TVA is used.
General Services Administration	4.5	Estimated productivity of capital.
Department of Agriculture	4.875 to 5.0	Treasury borrowing cost.
Office of Equal Opportunity	3.0 to 5.0	Estimated rate of return on a safe investment and a slightly higher rate.
Federal Avaition Administration	4.2	Federal Reserve rediscount rate.
Atomic Energy Commission	5.0 to 15.0	Sometimes Treasury borrowing cost used, sometimes rate used by private utilities, sometimes "rate used in industry."
Department of Defense	10.0	Opportunity cost in private sector.
Agency for International Development	8.0 to 12.0	Opportunity cost, in U.S., and in foreign countries involved.
Department of Interior	3.1 to 12.0	Rate indicated in Senate Document 97 to average return in private sector.

Agency	Rate(s)	Rationale
Department of Health, Education, and Welfare	0 to 10.0	Various factors, depending on the circumstances.

Source: General Accounting Office Report, Survey of Use By Federal Agencies Of The Discounting Technique In Evaluating Future Programs, pp. 19-20.

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